MINISTRY OF TRANSPORT.

REPORT OF THE COMMITTEE

ON

MAIN LINE RAILWAY ELECTRIFICATION

1931.

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MINISTRY OF TRANSPORT.

COMMITTEE ON MAIN LINE RAILWAY ELECTRIFICATION.

Members of Committee:

The Right Hon. Lord WEIR OF EASTWOOD, *Chairman.*

Sir RALPH WEDGWOOD, C.B., C.M.G.

Sir WILLIAM MCLINTOCK, G.B.E., C.V.O.

Secretary:

Colonel A. C. TRENCH, C.I.E., R.E. (ret.)

STATEMENT OF EXPENDITURE.

The expenditure incurred by the Committee including the estimated cost of printing and publishing this report is £5,456.

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To the Right Hon. HERBERT MORRISON, M.P.,
Minister of Transport.

PART I.

GENERAL REVIEW.

SIR,

1. We were appointed in September, 1929, with the following terms of reference :—

"In view of the progress which is being made towards widespread availability of high tension electrical energy, to examine into the economic and other aspects of the electrification of the railway systems in Great Britain, with particular reference to main line working, and to report their conclusions."

A further official statement was made to the effect that our investigation was not to stand in the way of, or affect, the adoption of any proposed schemes of further suburban electrification by the railway groups, including the semi-suburban scheme of the Southern Railway to Brighton.

2. We have held 31 formal meetings, and taken evidence from 19 witnesses (See Appendix I) regarding the many technical, commercial, and economic matters involved in the general problem, and to these gentlemen we tender our high appreciation of the assistance they have given to us. We are indebted especially to Mr. J. M. Kennedy for the remarkable degree of thoroughness and detail which he devoted to the preparation of his comprehensive general estimate and evidence, and the time and attention which he and his firm have given to its revision and strengthening. We also pay a willing tribute to the admirable spirit of co-operation and help shown by the General Managers of the British Railway Companies and the various members of their staffs, and would mention in particular Mr. H. W. H. Richards of the London and North Eastern Railway who has undertaken a very large amount of work for our assistance.

Valuable information has been obtained by Mr. Sherrington of the Railway Research Service through the courtesy of the administrations of the Paris-Orleans Railway, and the New York, New Haven, and Hartford Rail Road. The Headquarters of the Swiss Federal Railways were good enough to afford facilities to our Secretary to enquire into certain points on which their practical and extensive experience of electrification was of much value, and to all these Railways and especially to Dr. Huber Stockar, Technical Adviser of the Swiss Federal Railways, we desire to express our thanks for their assistance.

3. After a preliminary survey of the general situation of British railways we came to the conclusion that, whatever our detailed investigations might disclose, and whatever conclusions we might reach, the nature of our analysis and the conclusions should be as convincing as possible to those who control the policy of the railways of this country. At all times we were conscious that we were dealing with a problem of supreme importance to the railway companies, inasmuch as whatever might be the practical value of our work, the ultimate application of it would in the main fall on them.

Justification for Enquiry.

4. At an early stage it became obvious that the following words from our terms of reference give a keynote to the justification in the national interest for this investigation : "In view of the progress which is being made towards widespread availability of high tension electrical energy". In the past the railway companies of Great Britain have made various investigations into the possibilities of electrifying parts of their systems, but the advent of the national scheme of electrical power supply, the creation of the Central Electricity Board, and the national grid, introduced such entirely new factors into the problem of main line electrification as clearly to warrant a new and comprehensive review of the economic possibilities of a change in haulage practice from steam to electricity.

The British Railway System.

5. A large scale picture is essential to secure some measure of true perspective in regard to the main transport service of our country. Owned and operated by four great corporations, there exists in the railways an instrument the efficiency of which is vital to our national welfare, as providing the primary transport service to our industries and the community in general. This service is, generally speaking, operated by steam haulage, and the responsibility of proposing to change the haulage system of such a gigantic enterprise which, through its rates and charges, exercises a substantial influence on the costs of all industrial and other products and services and consequently on commodity prices and the cost of living, is as obvious as the national importance of realising any savings and economies which the march of science may render possible.

The following approximate figures (for 1929) give an outline of the extent of our British railway system (excluding the London Tube Railways and the Metropolitan District) :—

Issued Capital	£1,134,770,000
Number of Shareholdings	801,000
Number of Employees (Week ended 8th March, 1930)	646,000
Total Route Mileage	20,300
Total Track Mileage including sidings	52,500
Total Engine Mileage	593,519,000

Coal consumed by Steam Locomotives and Rail Motors (tons)	13,413,000
Steam Locomotives	23,400
Passenger Carriages (including Rail Motors)	49,300
Approximate number of Passenger Journeys	1,347,667,000
Merchandise and Mineral Traffic Vehicles	700,000
Goods and Mineral Tonnage transported (tons)	329,579,000
Live Stock transported (head)	17,700,000
Gross Receipts	£214,661,000
Net Receipts	£42,746,000
Salaries and Wages paid	£113,073,000

6. Any such general utility service to industry and the community must obviously rely for its future development and prosperity on the general progress of the country, industrially and agriculturally, and broadly speaking the policy of those who direct such a service is to a large extent conditioned by the needs and demands of industry and agriculture. In a country which is definitely progressive in productivity, it is axiomatic that the transport service must be provided on lines which are progressive in method, process, and efficiency, and with the high standard of living in this country the necessity for this policy is enhanced.

7. During recent years British railway transport has had to face two new and major phenomena—the growth of road transport both for goods and passengers, and the long spell of depression in many British industries, mainly those concerned with primary production. The effect of these two factors on the gross and net revenues of the Railway Companies is well-known and does not need emphasis. On the other hand we have found it impossible to form any precise or statistical estimate of their incidence.

In spite of this rather formidable shrinkage in railway revenues, we do not consider that any developments which have yet taken place are likely to displace the railways from their position as the main agency for the transport of goods and passengers in this country, or that the country's need of rail transport as a primary factor in production will diminish, however the character of the service needed or of the traffic to be conveyed may vary with the changing needs of industry. We have therefore approached the question remitted to us constructively, as one vitally affecting an industry which is itself vital to the future progress of British enterprise and production.

Faced with the two handicapping influences of road competition and depressed primary industries, it is quite apparent that, apart from the more normal efforts to achieve reduction in costs, the railway companies must be on the look out for and examine any more radical change in operating methods, such as a change in haulage system. Success in this search, such as may be possible, for example, through main line electrification, coupled with a revival or rejuvenation of industry, should enable the railway systems to retain for long their natural position of supremacy in national transportation. Accordingly, it is in that general spirit that we have attacked our task, and this task we define as follows: To establish as clearly and convincingly as we can, within the time available to us, the extent to which a change from steam to electric haulage on the main lines of our British railways would be economic and justifiable.

Interpretation of " Main Lines."

8. So far as we have been able to establish, all electrification of suburban railways in this country has been successful from an economic and technical aspect, while in addition the service to the community has been substantially improved. Accordingly, it may reasonably be assumed that the railway companies will in due course extend the electrification of their suburban lines in London and round about important provincial towns. The list of schemes in hand, to some extent, bears this out. On the other hand, we have been unable to find any strong spirit of conviction in railway circles to warrant a belief that any schemes, comprehensive or sectional, dealing with main lines are likely to be adopted. It is true that sections of the main line have been investigated by the companies, in some cases in considerable detail, but although some of these investigations showed economic possibilities, none of the schemes were finally adopted. Later in this report the difficulties and handicaps associated with such sectional schemes will become more apparent. It is also obvious that no general scheme of main line electrification is possible without the inclusion of the admittedly helpful suburban lines which are not yet electrified. With these considerations in view, we decided to regard " main lines " as all railways in this country not yet electrified or in process of electrification, with the exception of some spur or branch lines carrying little traffic. In regard to the latter we feel that the final decision on the best method of traction would require to be left to special investigation. However, as the ratio of such lines, expressed in revenue or ton-miles is small, and as it is quite impracticable to extract from the annual accounts the specific cost of operation and other essential figures from those attributable to the whole railway system, we decided in all our conclusions and estimates to include such lines, so that it is important to note that this procedure rather weights our figures against electrification.

Existing Railway Electrifications in Great Britain.

9. With the exception of a small section (18 Route miles) of mineral line on the London and North Eastern Railway, no main line electrification has taken place in Great Britain.

On the other hand, substantial progress has been made in the electrification of suburban and metropolitan lines, particularly around London, the total mileage at the end of 1929 being as follows (Tube lines excluded) :—

	Route Miles.
Southern Railway	276
Metropolitan Railway	31
Metropolitan District Railway	25
G.W.R. (London area)	7
L.M.S.R. (London area)	45
L.M.S.R. (Lancashire areas)	60
L. & N.E. (Tyneside area)	32
Mersey Railway	5
Liverpool Overhead Railway	6
Total	487

In addition to these completed schemes, there are at the moment under construction or approved schemes for the following additional mileage :—

	Route Miles.
Southern Railway, Purley-Brighton and Worthing	51
L.M.S. & L.N.E. Joint, Manchester-Altrincham	9
L.M.S., Barking-Upminster	8

The Southern Railway's extension to Brighton and Worthing might almost be regarded as a main line scheme, but the grounds on which the Company decided to electrify are that the traffic is of a suburban nature and therefore that the additional facilities are likely to induce additional traffic.

On different dates the British railway groups have investigated the economic possibilities of electrifying various sections of their main line tracks, and we have been furnished with particulars of some of these schemes, none of which were actually adopted. The more important of these were as follows :—

N.E. Railway, York-Newcastle.
G.W. Railway, Taunton-Penzance.
L. & N.E. Railway, Sheffield-Manchester.

Existing Electrifications abroad.

10. There are a number of railways operated by electric traction abroad, both in use and under construction. The following table gives the approximate Route Mileages electrified in various countries :—

	Route Miles.		Route Miles.
Australia	256	Italy	1,013
Austria	443	Japan	215
Canada	40	Mexico	79
China	25	Morocco	150
Cuba	156	New Zealand	15
Czecho-Slovakia	30	Norway	143
Dutch East Indies	26	South Africa	194
France	1,048	South America	544
Germany	968	Spain	370
Holland	84	Sweden	726
India	151	Switzerland	1,542
		United States	1,870

These figures include both Suburban and Main Line Schemes.

11. In Europe probably the most outstanding example is the Swiss Federal Railway system where some 1,100 route miles or 66 per cent. of the total mileage carrying some 85 per cent. of the total traffic are operated electrically. (In addition to this the other railways in Switzerland have about the same percentage of electrically operated mileage.) A further programme of electrification is now in hand. The primary reasons in this case were the desire to be independent of foreign countries for supplies of coal and the development of the national resources of water power, in addition to which the steep gradients and long tunnels are technical factors which specially favour electrification. A very full investigation of the economics of electric traction as compared with steam traction, based on 1929 conditions, has shown a saving of about £200,000 for the year in favour of electric traction, after payment of all interest and amortisation charges. It should be noted that the capital involved in this case includes the cost of the Hydro Electric Power Stations and transmission lines, as most of the Electric supply for the Railways is generated in Power Stations built specially for this purpose. In addition to this small but definite margin of profit on Electrification, which it is stated is likely to increase in future, a number of other advantages have accrued which cannot be evaluated in terms of cash. The increased cleanliness and comfort from the passenger point of view and the acceleration of both passenger and goods trains have proved of very substantial benefit in combating road competition.

It may be said that in Switzerland, apart from the above quoted reasons of national policy, conditions are such that Electrification has proved itself remunerative already, but it is clear that the national considerations were the dominant factor in the adoption of the scheme.

12. In Sweden various lines, including the Stockholm Gothenburg line of about 280 route miles, mostly single track, have been electrified on similar grounds, i.e. use of available water power rather than imported coal. In this case gradients and tunnels are not a factor of any importance. The economics of this latter project (completed in 1926) were subjected originally to much criticism on the grounds that the traffic density, which is estimated at about 3.2 million trailing ton kilometres per *route* kilometre per annum, was insufficient to justify electrification, but a special investigation into the financial results of 1928, i.e., the third year of working, has shown that the scheme has covered all capital charges with an appreciable margin, apart from a number of other advantages which it is impossible to determine in terms of money, and the financial advisers recommended that a further programme of electrification should be prepared without delay. In accordance with this recommendation the electrification of the Stockholm-Malmo line is now in hand and others are contemplated.

13. In France the principal main line installations are those of the Paris-Orleans railway, which extends at present from Paris to Vierzon, 145 route miles electrified, and of the Midi railway, about 750 route miles electrified. In the case of the Paris-Orleans, apart from the high cost of coal south of Paris, the railway electrification scheme was intimately bound up with the development of the water power resources of central France and the linking of these supplies with Paris. This scheme is eminently one of national policy rather than railway economics, in fact it appears doubtful on the information available whether in the present stage the railway electrification is in itself remunerative. The Midi railway electrification also is a case of the use of available water power in place of coal from distant sources. In this case the Railway Company supplies, from its Hydro Electric generating stations, electrical energy for general use over a considerable area, with material benefit to the inhabitants and industries concerned. In a paper read by the Chief Engineer in November 1930 it was stated that the technical advantages in Railway operation were very considerable while financially the scheme showed a small profit after paying capital charges and taking account of the considerable sums realised by the sale of Electrical energy. Other French schemes are at present limited to suburban lines, and mountain sections with steep gradients and long tunnels.

14. The various electrifications in Germany are attributable to a desire to use water power or in some cases local coal which is unsuitable for locomotives, also to the existence of heavy gradients and tunnels.

15. In Italy again the extensive electrifications are mainly justified in that they utilise available water power in place of imported or costly coal, in addition to which the existence of long tunnels and heavy gradients are factors in favour of electrification. The same considerations apply generally to the lines which have been or are being electrified elsewhere in Europe.

16. There are a number of electrified lines in the United States and elsewhere, but apart from systems of a suburban nature and city terminals the reason for conversion has been either the existence of severe gradients and tunnels, or an urgent need to increase traffic capacity, these reasons being frequently combined.

In this connection attention may be drawn to the impressive scheme of the Pennsylvania Rail Road, initiated in 1929, for the electrification of its main lines from Newark, just outside New York, to Philadelphia and Washington. This project will when completed make a total of about 800 route miles or 2,700 track miles electrically operated on the Pennsylvania system. Among the reasons which led to the adoption of this scheme are the economy of electrical operation in dense traffic areas, the increasing density of both goods and passenger traffic, the more rapid movement likely to be required, and the advantages of electric traction in new city passenger terminals.

17. It may fairly be said that the reasons which have led to the great majority of main line railway electrifications abroad are such that they do not apply to the same extent to British conditions, where coal supplies are ample, hydro-electric resources scanty, and, generally speaking, there are few severe gradients or long tunnels. On the other hand we are satisfied that there is no adequate foundation for the idea, so generally prevalent, that the scarcity of water power resources in Britain is in itself sufficient to render railway electrification uneconomical; at present prices of coal it is possible to generate electricity in a system of interconnected steam stations at a cost which compares favourably with that of the majority of hydro-electric developments.

British Suburban Electrification.

18. The general economic success which has characterised the adoption of electric haulage for metropolitan and suburban lines may be stated shortly as the ability of electric haulage to handle dense passenger traffic with heavy peak loads morning and evening, and thus to provide a service to travellers which it is difficult to obtain by steam haulage. In addition, the absence of smoke is an amenity of considerable value on lines with a large proportion of tunnels, and generally in city areas. Further, it has been clearly established that the more rapid and better service has had in every case the effect of bringing about large

increases in the traffic, better trade has followed better service, a noticeable feature being the growth of the off peak load and the increased inter-suburban traffic. As an example of this, taking a group of 18 stations on the Southern Railway situated between 9 and 14 miles radius, within four years from the date of electrification, the number of season ticket holders has increased 138 per cent., the number of other tickets issued 50 per cent., and the total passenger receipts almost 50 per cent. To attain this result the train mileage has been increased almost 100 per cent., but the additional cost of electric operation of this increased train mileage has been much less than the increase of revenue resulting therefrom. To a considerable extent the growth of satellite house building schemes has followed close on the provision of better transport service.

19. One of the effects of the development of demand following on improved service has been to make it quite impossible to establish any sound comparison between the costs of operation of steam and electrical haulage on suburban lines, because in every case the adoption of electricity has vitally altered the traffic conditions and no comparisons can be set up. Where electric haulage has been adopted on suburban service, the railway companies have found themselves in the position of having a transport machine of such improved capacity as to secure very rapidly an increased revenue. For these reasons we have found it quite impossible to obtain any useful comparisons between steam and electric haulage costs of suburban services which might be utilised in regard to our main line haulage investigation, where, of course, the possibilities of increased traffic are clearly less, and where mineral and goods traffic enter into the problem.

20. We were informed that the proposals for the Brighton extension of the Southern Railway electrification would involve an increase of between 100 per cent. and 150 per cent. in passenger train mileage and that the scheme would be justified financially if as a result there were an increase of 7 per cent. in the passenger traffic. The goods traffic on this line will not at present be electrically operated so that the whole of the capital charges of electrification have to be borne by the passenger traffic.

21. It may be said that suburban electrification is undertaken with the intention of attracting a considerable increase of passenger traffic by the provision of a much improved service, the additional cost of which will be substantially less than the additional revenue anticipated therefrom.

In the case of main line electrification on the other hand, although it is reasonable to anticipate that the additional facilities and amenities will in fact lead to some increase of traffic, the case must in general rest on the economies to be effected in handling existing traffic only, and no such increase can safely be assumed in any conservative investigation of the economic aspect of such a scheme.

At the same time we note that :—

(*a*) the capital cost of suburban schemes per track mile is necessarily high as compared with main lines

(*b*) even so, the fixed charges can be borne economically by a proportion only of the total traffic, the remainder being still steam-hauled.

(*c*) the cost of electrical energy on existing suburban schemes is higher than the price at which it could be supplied for a general electrification scheme and

(*d*) the average traffic density of typical suburban schemes is but little greater than that carried on a considerable mileage of main lines.

These considerations seem to indicate prima facie that the economic possibilities of main line schemes are encouraging.

Electric Power Supply in Great Britain.

22. One of the major elements of haulage cost is necessarily that of energy supply, which in steam haulage is represented by the cost of fuel (in Great Britain—coal), and in electric haulage the price paid by the railway for electrical energy. It has been pointed out that the relative sources of supply and cost of fuel and of available electric energy have been potent factors in deciding railway electrification schemes in certain foreign countries. Where coal has to be imported and is relatively expensive, and where electrical energy can be obtained at reasonable cost from water power, the case for electrification is considerably strengthened. In this country such conditions do not arise, as coal is relatively cheap, and available water power is almost negligible.

23. Up till 1926 any scheme for railway electrification involved a careful study as to the most economical method of obtaining a power supply, whether the energy should be purchased from an authorised undertaker or whether the railway should build and operate its own power station. In 1926 a revolutionary change was initiated in Great Britain by the passage of the Electricity Act, under which the generation of all high tension energy was placed under the control of a new body termed the Central Electricity Board, who were charged with the duty of inter-connecting generating stations through what is now known as the National Grid. Under these conditions it has been estimated that high tension energy will be produced and be made available in Great Britain at very low cost, certainly at lower costs than could be hoped for from individual and independent generating stations. In these circumstances it is obvious that no question can arise as to the source of electrical energy for any proposed scheme of railway electrification. The grid supply will be available and

should be utilised. In the Weir Report of 1925 on which the 1926 Act was based, paras. 100-102 are as follows :—

" *Railway Electrification.*—Although the matter is perhaps not strictly within our terms of reference, we could not fail to note the effect which the advent of the ' gridiron ' would have on the possibilities of the electrification of British Railways. At the same time we have made no allowance in our calculations for the possible demands over and above the present slow rate of growth of the traction demand. We definitely recommend that the Board should have power to supply railways direct.

" The existence of the ' gridiron ', the layout of which from the point of view of wayleaves must necessarily conform in a considerable measure to that of the railways, cannot but have a vital influence on reducing the amount of capital required for electrification. The availability of ample supplies of cheap energy from the ' gridiron ' would also relieve the railway companies from the necessity of heavy expenditure for power stations. At the same time a railway demand for energy, which might approximate to 20 per cent. of the whole national demand for other purposes, would most favourably affect the national load factor and thus reduce still further the cost of energy.

" The position would be so radically altered that we think that if the Government adopt our proposals generally, then at the same time they should take steps to ensure that Railway Electrification is reviewed and reconsidered."

Influence of Railway Electrification on National Electricity Scheme.

24. With these considerations in view, we asked the Central Electricity Board to give us an authoritative pronouncement on the reactions of a possible railway load on national electrical development. Their reply is as follows :—

" Important beneficial reactions will result to the general electrical development of the country as a consequence of adding railway electrification to the national Grid System.

" (*a*) In the schemes prepared by the Electricity Commissioners and adopted by the Central Electricity Board the growth of the load of authorised undertakers alone is estimated to be such that in every area existing selected generating stations will have to be extended to their full capacity within the next few years, and before 1940 new generating stations will be required. The addition of a large demand for railway electrification will have the effect of considerably accelerating the construction of such new generating stations and adding materially to their number. A close examination of the trend of power station design and the results already achieved in this country and elsewhere lead to the conclusion that the cost of energy sent out from such new power stations will be substantially less than the present cost at even the most efficient selected stations. The *average* cost of production will thus be reduced more rapidly than would be possible without railway electrification.

" The diversity which would undoubtedly exist between the demands of the Railway Companies and those of Authorised Undertakers from the Grid System would also have a favourable reflection in the cost of generation for both parties.

" (*b*) The use of the Central Board's primary 132,000 volt transmission system jointly for supplies to railways and authorised undertakers will result in a lowering of the Board's charge to authorised undertakers in respect of transmission and administration, for the reason that certain of the main transmission lines now being erected will not normally be fully loaded for the purpose of supplies to authorised undertakers and can, therefore, be used in part for supplies to the railways, while the average cost of primary substations will be improved, since the cost of extensions will be less per kilowatt of demand than was the original cost, as the land, and to some extent the structures, will be common both to the original and to the extended substations.

" (*c*) The secondary lower pressure transmission system which will be required to distribute energy from the Board's main Grid substations to the substations feeding the railways could, in many instances, be combined with the Board's secondary lines supplying authorised undertakers. The cost of secondary transmission to authorised undertakers would thus be lower than would be possible were no electrification of the railways undertaken.

" These are important considerations when it is remembered to what extent general expansion—and in particular industrial expansion—of the use of electricity is aided by every lowering of cost. But quite equally important is the consideration that the development of rural electrification will be greatly accelerated, for the secondary lines feeding the railway substations could be tapped to afford general supplies in many areas which, owing to their sparsely populated nature and low demand for electricity, could not commercially be supplied if it were necessary for them to bear themselves the full cost of the necessary transmission lines.

" The price calculated by the Board for Railway supply reflects a reasonable portion of the economies which would result from the accession of the railway load to the National Grid over the next 10 years. The price is thus lower than it would be possible to achieve if the existence of the Grid had not enabled the railway load to be pooled with that of authorised undertakers."

Electricity Supply Rights.

25. The statutory right to supply electrical energy in the area of an Authorised Undertaker belongs to that Undertaker, and the Central Electricity Board may not supply energy to anybody in the area. As we have seen in the Weir Report, it was recommended that in the case of Railways the power to supply should be granted to the Central Board. Parliament did not, however, carry out that recommendation but laid it down that Undertakers must pass on a supply, which they purchased from the Board, to a Railway Company at cost price plus such charges and allowances on transmission lines as are defined in the Third Schedule to the Electricity (Supply) Act, 1926. The outstanding reason for the recommendation in the Weir Report is obvious, as a Railway runs through the territory of many Authorised Undertakers, some small, others large. In a great main line electrification scheme, it is clearly impracticable for a Railway Company to make individual Agreements, which are necessarily elaborate, with a number of independent Undertakers. Such divided responsibility and the difficulties of co-ordination would be definitely harmful to a comprehensive scheme of supply. Moreover, it is clear that the demands for electrical energy from the substations along a main line will not coincide in time, and were such individual demands to form the basis of the charge to be made by each Undertaker the result would be inequitable and uneconomic. Nevertheless, any arrangement designed to co-ordinate the several contracts with different Undertakers to provide against this would be so complex as to be well nigh impossible. We conclude, therefore, that the original proposal should be adopted and the Central Board be given power to afford direct supplies for railway electrification schemes.

It has also been brought to our notice that under existing legal provisions, a Railway Company taking a supply of energy from a supply authority at any point, is not permitted to use this supply for lighting or other auxiliary purposes in any area outside that of the supply authority except under special consent of the Minister of Transport.

We consider, as a corollary to our conclusion above (that the Central Board should have power to supply Railways direct) that the Railways should be authorised to use such supply for any purpose of their own at any point on their system.

Arrangements for Supply to Railways.

26. We have considered four schemes in regard to the best method of arranging for power supply to the railways. The most extreme suggestion has been that the Central Electricity Board or a new subsidiary body working in conjunction with the Central Board should provide the transmission lines, sub-stations, and overhead track equipment, and enter into a contract with the railway companies for the supply of energy delivered at the pantograph of the locomotive or other haulage unit. Such a scheme would result in reducing to a minimum the capital outlay by the railway companies and would leave to them merely the supply of the electric tractors, necessary alterations to structures and signalling, etc. On the other hand, this arrangement would in practice obviously result in difficult questions of divided responsibility and operation, apart from the difficulties of an outside authority working with the railway staffs on railway property. This suggestion we dismissed.

The next proposal is for the Central Electricity Board to provide the transmission lines, to build, equip, and operate the sub-stations and supply the converted energy to the railway companies at the track feeders. The alternative is for the Board to supply the high tension energy to the railway companies at the sub-stations, leaving the railway companies with the ownership and operation of these sub-stations.

After careful consideration we have adopted as a basis for our calculations a proposal that the Central Electricity Board should provide the transmission lines, build and equip the sub-stations, and supply energy to the railway companies at the Direct Current busbars of the sub-stations, but that the operation of the sub-stations (and the control in the case of remote controlled sub-stations) should be carried out by railway employees. The evidence before us leaves no doubt that such operation and control must essentially be in the hands of the railway staff.

The alternative scheme, under which the sub-stations would be built, equipped and operated by the Railways, who would take their supply at the high tension busbars of the sub-stations, should not affect the final cost of electrical energy except in such degree as the Interest and Sinking Fund rates adopted by the railways may differ from those of the Board. It would, however, involve a considerable addition (of the order of £30 millions) to the capital expenditure to be undertaken by the railways (and a corresponding deduction from that to be found by the Board) and for this reason we think that the former arrangement would be preferable.

Price of Electrical Energy.

27. In view of our conclusion that the supply of energy must be taken direct from the Central Electricity Board, we instructed our professional advisers that, for the purpose of the detailed investigations described hereafter, they should ask the Board to quote the price at which energy could be supplied for a general scheme of electrification of the whole railway system of the country.

In reply to this request the Board quoted a price of 0.5 penny per Kilowatt Hour for the necessary supply of Direct Current Energy, delivered at the Direct Current busbars of sub-stations, *i.e.*, on the assumption that the Board would provide and instal all necessary

transmission lines, substations and plant, but the Railway Companies would maintain and operate the substations. This quotation was subject to a coal clause, to the payment by the Railway Companies of local rates on the substations, if any, and was based upon a load factor of 50 per cent. On the data available it would appear that a load factor of 50 per cent. should be obtainable for a comprehensive scheme, on which the daily peaks and nightly cessation of suburban services should be neutralised by the goods and all night traffic of main lines.

In reply to a subsequent inquiry the Central Board stated that, provided the total railway load increased as estimated to a final figure of about 6,000 million K.W.H. per annum (Substation output) for complete electrification in about 20 years' time, it might be estimated that the price would by that time be reduced to 0.475 penny per Direct Current unit.

A figure of 0.5 penny has therefore been assumed in the detailed investigations referred to below, and a figure of 0.475 penny in our general estimate for complete electrification.

System of Electrification.

28. We have not considered it necessary to go into technical details in connection with the choice of the most suitable system of electrification, in view of the fact that such questions were fully investigated by the Committee appointed in 1927 under the Chairmanship of Sir John Pringle. This Committee reported in 1928 in favour of two alternative standard systems which are, in substance—Direct Current overhead with a maximum pressure of 1,500 volts and Direct Current third rail with a maximum pressure of 750 volts. The possible use of 3,000 volts Direct Current on the overhead system was also admitted; none of the expert evidence which has been submitted to us has questioned these recommendations, and we have assumed that they will be followed.

In the investigations made on our behalf our Consulting Engineers and the Railway Officers concerned selected the 1500 volts overhead system.

Alternative Systems of Haulage.

29. The essential characteristic of electrification as compared with all other traction systems is the removal of the generation of power from the train. All other systems involve carrying the power generator on the train. Later it will be seen that this characteristic is responsible for most of the advantages and economies arising from electrification. Before a train can move under electric power a very large addition must be made to the capital account for expenditure on transmission lines, sub-stations, and track equipment, all these items being fixed and immovable. It is for this reason that the electrification of a railway becomes a problem requiring the most careful consideration. To-day with steam haulage it is, of course, open to a railway company to take advantage of any alternative form of tractor, such as an improved steam locomotive, a turbine locomotive, an oil engine, or an oil electric unit. It is merely a case of substituting one independent unit for another, whereas with electrification it is impossible to change the system without rendering useless a large proportion of the capital expenditure. Electrification of an existing system means the incurring of a heavy new interest charge on fixed equipment, and then the replacement of independent coal burning locomotives by dependent electric haulage units.

30. With these considerations in view we have felt it necessary to make some investigation into the value and importance of other alternatives to the existing steam locomotives, such as turbine locomotives, unconventional high pressure locomotives, petrol units, oil engined and oil-electric units. Without going into details we found that development is steadily taking place in the steam field and greater fuel economies are likely to be realised, but that it is probable that such fuel economies will be offset to a large extent by additional repair and maintenance charges and the higher capital cost associated with these new developments.

The most important alternative to the steam locomotive other than electrification is undoubtedly the oil engine. Here we have a prime mover of high fuel economy, requiring practically no water, while the storage and distribution of the fuel is simple. Unfortunately the general speed torque characteristics of the oil engine are inferior to those of the steam engine. In order to overcome this difficulty electricity has been adopted in the oil-electric locomotive as a means of connecting the oil engine to the wheels. Investigation of the use of oil-electric sets on trains discloses, however, that for a line with a frequent service, it would appear more economical to take the oil engines off the trains and put them in fixed generating stations supplying electric current to the moving train. This would result in a smaller number of oil engines being required on account of the improved load factor, so that the first cost would be reduced, the efficiency increased, and the weight of the moving train reduced. Conversely, it is evident that where the traffic is light it would pay better to put the oil engine and electric generator on the moving train. It is obvious that on national grounds preference should be given to home produced coal rather than to imported oil, to the extent that, whatever services can be operated with at least equal economy on coal should continue to use coal; moreover, it is certain that the coal fired power stations feeding the grid can supply power to the substations more cheaply than could oil engines located therein.

A further alternative which would be less dependant on a centralised supply system than electrification, would be the employment of battery driven locomotives, but we have been unable to obtain any evidence to guide us as to the prospect of such radical improvements in battery design as might make this feasible even for light units.

31. From all the evidence we conclude that none of the alternatives to steam which we have examined is either sufficiently developed to warrant widespread adoption as an alternative to the steam locomotives of to-day, or even holds the probabilities of development into an effective alternative to electrification for main line purposes. We would say, however, that, in the case of oil electric units, these may be regarded as possible substitutes for steam on lightly loaded branch lines, and more particularly so in conjunction with a general electrification of main lines.

32. Several witnesses have drawn our attention to the advantages of Multiple Unit equipment as compared with Electric Locomotives, mainly in reduction of total train weight and saving in terminal movements and shunting. Although there are certain classes of traffic for which Multiple Unit equipment is inherently unsuitable, we feel that there is on British Railways a very considerable field in which the use of such stock would be convenient and economical. This opinion was confirmed as a result of one of the detailed investigations referred to hereafter and we have based our estimate on this assumption.

Advantages of Electrification.

33. The direct financial advantages of electrification are expressed in the estimates which follow, and the benefits to the national electric supply system are embodied in the statement by the Central Electricity Board in para. 24 above. In addition to these there are a number of other advantages, many of which have a cash value, although it cannot be assessed with any accuracy.

(*a*) The overload capacity of an electric tractor permits an increased rate of acceleration, and an increase of average speed and speed on gradients so that it is possible to obtain a greater uniformity of speed among different classes of trains on the same track. In consequence of this, it is less frequently necessary to shunt a goods train to allow an express to pass, and as a result the overall speed of the goods train can be much improved while at the same time the capacity of the line is increased, thus avoiding possible capital expenditure on widenings, quadrupling etc. The same factor provides an increased capacity for making up time and hence greater punctuality. Typical examples, taken from the detailed investigations referred to hereafter, show a reduction in the journey time of a stopping passenger train from 2 hours 32 minutes (steam) to 2 hours 8 minutes (electric), and a similar reduction on a fitted freight train from 3 hours 48 minutes to 3 hours 1 minute.

It should be noted that although the speeding up associated with electric traction involves increases of average speed we have not contemplated any material increase of the maximum speeds already attained by the faster expresses.

(*b*) The capacity of terminal stations is increased by the use of multiple unit stock and the fact that electric locomotives do not require water, coal or turntable facilities. Shunting movements and signalling are much reduced and traffic movements expedited.

(*c*) The abolition of smoke and steam must have a substantial effect in reducing corrosion and dirt and thus on the expenditure on maintenance, painting and cleansing of structures and vehicles. Since electrification the Swiss Federal Railways have effected an appreciable reduction in cost of maintenance of permanent way in tunnels owing to the safer and easier conditions of work therein.

In large towns the abolition of locomotive smoke would be of considerable benefit to those living near the railway, and would enhance the value of adjoining property.

From the passenger's point of view the amenities afforded by the elimination of smoke especially in tunnels and the reduction of dirt and noise are an appreciable attraction.

The same consideration suggests the possibility of the development of " air rights " over electrified terminal stations, as has been done in the United States, where large blocks of office and other buildings have been constructed over terminal station areas in places where the value of land is high enough to justify the cost. In connection with any reconstruction of Charing Cross Station for instance, it seems probable that if the station can be designed for all electric working this consideration might be of material advantage.

(*d*) The even torque of the electric locomotive and the absence of hammer blow together with other features of suitable design make it possible to provide an increase of power on a limited axle load with the result that it will in some cases be possible to avoid renewal or strengthening of bridges. It has been found also on electrified lines that the maintenance of coupling gear has been materially reduced by the even torque of the electric motor.

(*e*) The driver of an electric locomotive or motor coach has a better view of the line ahead, an important aid to safety, while his personal comfort is very materially enhanced. It is true that the structures supporting the overhead equipment tend to restrict the view of signals, so that in any estimate provision must be made for alterations to signals in order to maintain adequate visibility.

(*f*) Apart from the increased capital burden involved in electrification, the actual operation of train haulage can be performed more cheaply by electric traction than by steam traction, and the operation of additional services is thus more economical with electric than with steam working. This applies not only to the provision of additional excursion facilities, but also to the provision of a more frequent service of lighter trains on sections where the traffic is likely to respond to an increase of frequency. Flexibility of operation is thus increased, and full advantage can be taken of the cheaper cost of electric haulage.

(*g*) The avoidance of fires caused by sparks from engines is a minor but definite advantage.

Disadvantages of Electrification.

34 (*a*) Apart from the heavy capital expenditure involved, the disadvantages are, comparatively speaking, of a minor nature. The first of these is the fact that a failure in the supply of energy may stop a number of trains, whereas at present an engine failure only directly affects the one unit. Experience on electrified lines proves, however, that any extensive failure of supply is an occurrence of such rarity and such short duration that the risk is not a serious one. With the inter-connection afforded by the Grid and the alternative sources of supply available, the risk should in most parts of England be even further reduced.

(*b*) Although the risk of failure due to accidental causes may be slight, from the national point of view it is clear that an electrified system is more open to attack and disorganisation by enemy or ill-disposed persons than a system operated by self-contained tractor units, and this is probably the most serious aspect of the matter.

(*c*) The use of an uninsulated return circuit through the running rails involves some risk of stray currents causing electrolytic damage to cables, pipes and similar metal bodies in the immediate vicinity of the track. There is also the possibility of inductive interference with communication circuits near the line. These points were considered by the Pringle Committee, referred to in para. 28 above, who expressed the opinion that safeguards could be provided by suitable bonding and similar arrangements adequately maintained. The electrolysis risk would, however, still further restrict the possibilities of steel sleepers with the overhead system, and these are in any case impracticable with the third rail system.

(*d*) In the case of third rail systems risk of electric shock is involved for permanent way men and others whose duties necessitate working on or walking along the lines. Experience shows that the cases of this are not frequent, but the extra care required does increase the time and cost of track maintenance, and it is generally agreed that third rail would be impracticable in yards. With the overhead system the risk of shock should be negligible but the maintenance and the time taken to repair in case of accident are likely to be greater than with third rail.

(*e*) In both systems the risk of fire caused by a short circuit after a derailment is a possibility but hardly a serious consideration.

The Speculative Aspect.

35. In considering any large capital expenditure and in estimating the financial results, it is essential to bear in mind not only whether sufficient allowances have been made for upkeep and depreciation, but whether from the point of view of speculative future development the expenditure is likely to be an asset of permanent value. The expenditure on electrification of railways is mainly represented by apparatus already of very high efficiency and therefore capable of no outstanding improvement in the future. The sub-station machinery and the motors on the trains have very high efficiencies and obsolescence is therefore bound to be relatively small. In this respect electrical apparatus is in a different category from either steam or internal combustion plant. In electrification the part of the system which must be written down is in the power station, because it may be expected that on account of its relatively low efficiency it will be liable to steady improvement. In the case we are considering the expenditure on this plant in the power station would of course not fall on the railways, and as and when improvement takes place, the price of electricity to the railways will be gradually reduced by the adoption of the improved apparatus.

On the other hand, it is proper to consider the speculative possibilities of alternative systems of transport, as differentiated from alternative systems of rail haulage. We have in para. 7 already expressed the view that no existing development appears likely to displace the railways as our main transport agency, but in expressing this view we cannot evade recognition of the possibilities of road transport. There are no data to indicate the real relative costs of transporting by road or by rail the wide range of traffics now dealt with by railways, and it is therefore difficult to form any authoritative judgment, but within the bounds of reasonable speculation we cannot anticipate the general supersession of railways by roads.

The only other speculative development which would affect obsolescence in the fixed capital expenditure on electrification (and which might also affect road haulage) might be in the field of electric storage batteries. We feel that the prospect of such development for heavy traction is inherently a remote one, and, as noted in para. 30, the possibilities for light units are still quite indefinite.

PART II.

THE ECONOMIC INVESTIGATION.

Field for Savings in Haulage Cost.

36. Having now established the more general considerations associated with electric traction we proceed to the application of them in a definitely economic sense, but we consider it essential to indicate in the first place the field of existing expenditure over which any savings or economies have to be realised.

The components of haulage cost directly affected by electrification are in general the cost of wages, fuel, water, stores, etc., for operating, maintaining and renewing locomotives; in addition to these the wages of guards and the cost of cleaning vehicles afford definite scope for a reduction in costs on electrification.

A number of other items which are mentioned in para. 33 (Advantages), are also of certain financial benefit, but we have not considered it possible to assess definite cash values to them and we have therefore omitted them from our estimates, which are to that extent weighted against electrification.

In 1929 the total of the above costs for the steam operated Railways of Great Britain amounted to about £54,760,000 or 23.5 pence per engine mile; out of this the most important items are :—

	Pence.
Locomotive and Shed Wages	9.0 or 38 per cent.
Locomotive repairs and renewals	5.6 or 24 per cent.
Fuel	5.3 or 22 per cent.
Guards' Wages	1.8 or 8 per cent.

The balance of 1.8 pence (8 per cent.) comprises maintenance of locomotive buildings, water, lubrication, stores and clothing, cleaning of vehicles, National Insurance and miscellaneous.

All our investigations show that on the item of fuel comparatively little saving will be made by the substitution of electrical energy, in place of coal (at existing prices), and even though a saving of about 50 per cent. may be realised on the total of 1.8 pence for minor items, the net gain will be comparatively small. It is therefore in the field of locomotive wages and locomotive repairs that electricity must establish its economic gain.

The total of locomotive and shed wages will be largely reduced by reason of the facts that an electric locomotive does not require the time spent in lighting fires, raising steam, coaling and watering, cleaning fires, movements to turntables etc.; and daily cleaning and maintenance services will be considerably reduced for each locomotive, apart from the fact that the total number of tractors is likely to be reduced by over 30 per cent owing to the much larger annual mileage obtainable from electric tractors. In addition to this, there will be some acceleration of many of the slower services, double heading, where necessary, will not entail a crew on the second engine, and there will be a considerable extension of multiple unit operation on which, with the " dead man's handle " equipment, one motorman only is required in place of the two men on a steam locomotive. Similar arrangements would be adopted on shunting locomotives and, subject to certain limitations, on train locomotives.

Considering locomotive repairs, the electric locomotive is, as regards wear and tear and overhaul requirements, a far simpler apparatus than the steam locomotive; the elimination of the boiler and reciprocating parts in particular is a most important factor, and it is well established by extensive experience that the frequency and extent of periodical overhauls are far less with electric locomotives than with steam.

In the case of the smaller item of guards wages it has been ascertained that the increased overall speed of a large number of the slower trains will effect a material reduction in this charge

We should, however, make it clear at this point that our calculations have been based on existing rates of wages, and, wages items being the dominant factor, any appreciable alteration in railway wage rates would modify the result of our calculations.

The Necessity for Detailed Investigations.

37. In striving to obtain reliable comparative costs of steam and electric traction in actual working we have been entirely unsuccessful. In Great Britain the successful results of suburban electrification are, as we have seen, due principally to increased business. The foreign figures and experience are affected by conditions which do not apply to Great Britain. Generally we found that each electrification scheme differs so much from another that generalisation is risky. What can be said with confidence is that electric traction has shown itself to possess definite elements of superiority over steam traction, and that the system is being extended wherever it has been adopted.

Faced with this situation we decided to investigate the possibility of obtaining a professional report based on a detailed examination into the electrification of a complete British railway system. We found, however, that this would occupy an unreasonably long period and would impose an undue amount of work on the railway staff. It will be appreciated that such an examination involves, besides a fairly complete survey of the line to ascertain

the cost of equipment and alterations, and many other investigations, a very considerable amount of work in rearrangement of time-tables. The time, labour and expense required to deal with all these questions in the case of a complete system would be greater than was in our opinion practicable. After consultation with the railway authorities, we decided to arrange for Messrs. Merz and McLellan to conduct two professional investigations into sections of British railway systems, in full co-operation with the Staffs of the Companies concerned, and we desire to express our appreciation of the very considerable amount of work they have willingly undertaken for our assistance.

The first scheme consisted of practically all that portion of the London and North Eastern Railway which was formerly operated as the Great Northern Railway, including both heavy through traffic, and light local traffic in sparsely populated districts like Lincolnshire, and with light average gradients.

The second scheme covered a portion of the London Midland and Scottish Railway consisting of main lines with heavy traffic in an area mainly industrial, and with some heavy gradients.

The conditions on the first of these two systems are fairly typical of the British railways as a whole, while those on the second system are rather more specialised, and include certain features which are usually favourable to electrification.

38. We laid down in regard to the first investigation that our professional advisers were to assume that all other lines were also electrified, i.e. there was to be no question of dual working. In regard to the second examination we laid down that the section chosen was in itself to be electrified but that it was to be assumed to remain surrounded by steam-working. In both cases it was to be assumed that the traffic to be handled would remain as at present, but that minor time table alterations and modifications in increase of average speeds and similar methods of handling might be introduced to suit electric operation.

We would note at this point that more radical alterations would probably be introduced in actual practice, in order to take the fullest advantage of the characteristics of electric operation, but we decided on the foregoing in order to avoid an unduly laborious investigation and to ensure that the most conservative basis was adopted.

Electrification of a steam railway, apart from the actual cost of the track equipment and tractors, involves a number of incidental alterations to way and works such as increase of structural clearances, additional protection, conversion of direct current track circuits to alternating current, metallic returns on block and other circuits, alteration of signals, etc. In many existing electrifications, where a large increase of traffic is contemplated, the signalling and other alterations have been of a very extensive nature designed to deal with this additional traffic, and the capital cost has been considerable. In our investigations, as no allowance is made for possible increase of traffic, we laid down that expenditure on works of the nature indicated above should be limited to items which are rendered necessary by electrification itself, such as resiting of signals, etc. and should exclude additional works which might be desirable for handling an increase of traffic.

Result of Detailed Investigations.

39. The reports of the experts are appended, but their main features may be summarised as follows :—

	L.N.E.	L.M.S.
Total route mileage	492	193
Total track mileage	1,944	843
Trailing ton miles per annum electric ...	6,000,000,000	2,225,000,000
Trailing ton miles per annum steam hauled.	—	395,000,000
Engine miles (electric)	21,000,000	7,950,000
Engine miles (steam)		1,590,000
Traffic density, trailing ton miles per running track mile per annum.	4,300,000	4,050,000
(Estimated comparable average density for whole country 3,000,000.)		
	£	£
Net capital outlay	8,646,000	5,123,000
Savings in working expenses	624,600	127,800
Percentage return on net capital	7·22%	...2·5%

The price of copper (wire bars) has been taken at £70 per ton, and coal has been taken at existing prices. A rise or fall of 1*s.* per ton in the prices of coal would increase or decrease the percentage return in the case of the L.N.E. investigation by 0·225.

Deductions from Investigations.

40. The results are at first sight somewhat unexpected, in view of the conditions referred to in para. 37 above. The L. & N.E.R. scheme shows a return of 7.22 per cent., while the L.M. & S.R. scheme, in an area of dense traffic and heavy gradients, shows only 2.5 per cent. on the net capital outlay.

It was clearly necessary to investigate more closely the conditions of the L.M. & S.R. scheme. Messrs. Merz and McLellan were therefore asked to examine further the reasons for the difference between the two schemes, and they say in their covering letter to the L.M. & S.R. Report (Appendix V) :—

" (i) Although in other electrification schemes electric shunting has proved profitable, in the present case it was decided, initially, in order to limit the scope of the investigation, not to include any arrangements for electric shunting in the main goods yards, and to equip only the entrances to the sidings, so as to enable the train engines to haul their trains into the yards. The mileage of track to be so equipped, however, proved to be much greater than was expected, and the greater part of the sidings had to be included.

" (ii) The electric locomotives under this scheme would work an annual mileage of about half as much as electric locomotives can do, and actually are doing to-day on other systems. This is mainly due to :

" (*a*) The comparatively small size of the scheme.

" (*b*) The amount of dual working (i.e. running part of a train journey with steam and part with electric locomotives).

" Thus, while the distance from Crewe to Carlisle is 141 miles, the average length of electric locomotive run for booked passenger trains is only 43 miles, and for goods trains 42 miles. The average annual mileage is 35,000 against a possible 70,000 or 80,000. Some of the locomotives, moreover, would lie over between turns for 15 or 16 hours per day, thus increasing both the number required and the cost of the crews. The railway officers, as the result of a special investigation, find that the steam engines now running, wholly or partially, on the sections to be electrified, cover a total of 15,800,000 miles per annum, of which about 5,800,000 are on lines outside the scheme. To do this mileage 614 steam engines are now used, of which 379 would have to be retained after electrification, and 220 electric locomotives added. Thus, while electrification would eliminate 53 per cent. of the steam locomotive mileage, only 38 per cent. of the existing engines would be released, and the total number of locomotives would be reduced by only 2½ per cent. If the electrification scheme were more extensive, and adjacent sections were included, the locomotives would be used to better effect."

In other words, a considerable part of the capital outlay mentioned in (i) would be practically unremunerative, while under (ii) the expenditure on locomotives (amounting to more than half the net total capital expenditure on the scheme) would, under the conditions laid down, only earn about half as much as it should do.

In the case of the L. & N.E.R. scheme on the other hand it was laid down as an assumption that all surrounding lines were electrified. In this scheme full use was made of the capital outlay and a reasonably high mileage estimated for the new traction units.

41. This explanation raises two questions affecting factors which are usually of primary importance in railway electrification, as in other uses of electric power, viz. the extent to which the financial results are affected by :—

(*a*) The size of the scheme.

(*b*) The extent to which the adoption of electric power is complete.

The supply of electric energy or gas is usually, other things being equal, more profitable on a large scale than on a small one, and pays better as the variety of uses and the amount consumed in a given area is increased. In like manner, the full advantages of railway electrification are only obtained when a considerable section is equipped and when practically all the traffic thereon is handled electrically. Just as the most profitable conditions for a railway to-day are those where it handles all the transportation in its area, instead of sharing it with other forms of transport, so electric traction is most profitable when the traffic on a particular section of line is wholly operated electrically, and not partly handled by steam. In transportation, as in other cases, when electric power enjoys a monopoly, it is correspondingly cheaper and more efficient than when it divides the work with some other agency.

To put it shortly, it is clear that the heavy first cost of the overhead equipment, and of electric locomotives, is only justifiable where adequate use is made of their capacity. To equip sidings and shunting yards for occasional use only, and to employ engines capable of doing 70,000 to 80,000 miles per annum, for only half that mileage, especially while retaining the use of steam locomotives, means all the difference between profit and loss.

42. The result of these investigations and of other inquiries has satisfied the Committee :—

(*a*) That except where some special conditions obtain, the carrying out, or even the investigation of, limited schemes, involving as they must the dual working of steam and electricity, is unlikely to prove worth while.

(*b*) That there is only one way by which the full benefit of railway electrification can be obtained in Great Britain, and that is by the complete substitution of steam haulage by electricity.

The extent to which any such programme is economically justified we now proceed to examine.

Estimates for General Electrification.

43. With the assistance of the data furnished by the two detailed investigations we resumed consideration of two general estimates for the electrification of the whole of the British Railway System which had been submitted by Mr. J. M. Kennedy and Mr. H. W. Richards; in conjunction with them we had the assistance of an outline sketch by Messrs. Merz and McLellan indicating in general terms their views on the application of the results of their two detailed investigations to the whole of the country.

In each case it was only possible to work on the Ministry of Transport figures for the whole railway system of the country and it was not practicable to eliminate from the estimates the appreciable mileage of light traffic lines on which electrification would not in practice be justified. It must be recognised also that such estimates can only be based on broad assumptions.

Mr. Kennedy's original estimate, embodied in a most valuable and comprehensive review of the question, was prepared in great detail and indicated a return of approximately 7.1 per cent. This was discussed with various officers of the L.N.E. Railway and thereafter revised and resubmitted. Subsequently on completion of Messrs. Merz and McLellan's L.N.E. investigation, which gave us entirely authoritative data of the first importance, the two estimates were compared and it was found that the majority of the items were in close accord.

Mr. Richards' estimate was prepared generally on different lines to the others and this also was revised and subsequently compared with the detailed investigation with similar results.

In both cases the final results indicated a slightly higher return on the capital cost of complete electrification than the 7.22 per cent. which was calculated on the L.N.E. scheme.

44. Although the assumptions and data in these estimates were in the main well supported and appeared to us to be generally reasonable, we felt that it was essential that our conclusions must be founded on a most conservative basis and that it would be imprudent to include as definite financial credits a number of items on which electrification will certainly produce some saving but the magnitude of which saving it is difficult to assess.

We decided therefore, that with all these proposals, both general and detailed, in front of us, and with all our other evidence, we should arrange for the preparation of complete general estimates of capital expenditure and the relative steam and electric working costs for the whole of the British Railway system. We consider that these estimates, which are given in Tables I and II, are on a conservative basis and may reasonably be regarded as being as sound and authoritative as any overall estimate can be without an actual survey and detailed professional examination.

TABLE I.

ESTIMATED CAPITAL COST OF ELECTRIFICATION OF ALL STANDARD GAUGE STEAM OPERATED RAILWAYS IN GREAT BRITAIN.

		£ millions.
(1) Track Equipment		129.7
(2) Auxiliary Power Cable		13.5
(3) Alterations to Way and Works...		13.7
(4) Electric Tractors		136.5
(5) Running Sheds, Shops, Stores, etc		4.5
(6) Spare Parts		5.5
(7) Auxiliary Power supplies		2.25
(8) Interest during Construction		12.5
(9) Engineering Expenses		5.0
Total gross cost		323.15
Credit Items.	*£ millions.*	
(10) Steam Tractors	45.5	
(11) Coal Stocks	1.38	
(12) Spare Parts	4.5	
(13) Locomotive Coal Wagons	2.4	
(14) Passenger Coaches	2.5	
(15) Surplus Plant, etc.	4.0	
(16) Train lighting sets	2.0	
Total Credits	62.28	62.28
Net Capital Cost		£260.87

Say £261 millions.

(17) Additional expenditure on generating plant, transmission lines, and substations, to be incurred by the Central Electricity Board and other Authorised Undertakers, approximately £80 millions. The economic return on this sum is included in the price to be paid for Electrical Energy by the Railways.

NOTES ON ITEMS OF CAPITAL ESTIMATE (TABLE I).

(1) *Track Equipment.* £129.7 *million.*—The total mileage of standard gauge lines not already equipped for electric working is approximately 36,000 track miles running line and 15,500 miles of sidings. Average rates of £2,500 per mile for the former and £1,800 per mile for the latter have been taken. These rates, in addition to the overhead equipment, include track feeders and bonding and 10 per cent. has been added for contingencies.

An average copper section of 1 square inch has been assumed for each running line and the price has been taken at £70 per ton for copper (wire bars). The quantity of copper involved for the overhead line alone would be in excess of 330,000 tons, so that it is evident that there would be a very substantial saving in capital cost if copper actually averaged anything approaching present prices (£47-10*s.* on 13/1/31). It seems possible that the use of steel cored aluminium cables might be practicable for a considerable portion of the catenary and this would no doubt be investigated if the relative prices of copper and aluminium justify it.

(2) *Auxiliary Power Cable* £13.5 *million.*—In the detailed investigations it was found advantageous to provide auxiliary power cables along the route, fed from all substations, for the purpose of supplying power and light at numerous intermediate points. The cost of this was estimated at £1,350 per mile, and it seems possible that provision of such cables might be desirable on a maximum of half (say 10,000 miles) of the total route mileage of the country.

(3) *Alterations to Way and Works*—£13.7 *million.*—This item showed very wide variations in rates per route mile in the detailed investigations, depending on physical conditions, the nature of the route, and the traffic thereon. The rates taken vary from £250 to £2,000 per route mile, based on a rough assessment of the proportions of route of the various categories.

(4) *Electric Tractors* £136.5 *millions.*—The cost of Tractors, including both Electric Locomotives and Multiple Unit equipments, has been estimated on two separate calculations of the probable annual mileage per tractor of various types. These totals were checked by the ratio of the annual ton miles to the cost of tractors found by the L. & N.E. investigation, suitably modified for the whole country. The results of the three computations were in close accord and the figure taken is the mean of the three and includes allowance for contingencies. The total allows for the provision of about 10,400 Electric Locomotives of suitable types and 4,800 equipments for 3 or 4 coach Multiple Unit sets, and includes equipment for carriage heating. In paragraph 54 we indicate the conditions which lead us to think that a substantial reduction may be anticipated on this total figure. For the purposes of this estimate we have assumed that the important question of carriage heating would be dealt with on the lines indicated in Messrs. Merz & McLellan's L. & N.E. report (Appendix IV).

Various Items.—The following are lump sum figures based as far as is practicable on the results of the detailed investigations.

(5) A sum of £4.5 millions has been included to cover alterations and additions to running sheds and repair shops and the provision of any necessary control offices and stores. It should be remembered in this connection that the repair requirements for Electric tractors are much less than those for Steam locomotives.

(6) £5.5 millions has been provided to cover the initial cost of a stock of spare parts for tractors, track equipment and substations.

(7) In order to utilise the general supply of energy for local power and lighting, transformers, switchgear, wiring and other alterations will be required at many points and £2.25 million has been allowed to cover the cost of this.

(8) A sum of £12.5 millions is provided to cover interest during construction. It is assumed that after the first five years, the average period between payment and beneficial use should not exceed 12 months, but that during the first five years the additional cost of dual working will swallow up the savings realised by partial electrification. This assumption results in a figure of £15.6 millions gross, from which is deducted the income tax allowance, bringing the final figure to approximately £12.5 millions.

(9) £5 million is included for general engineering expenses.

Credit Items.

(10) *Tractors.*—A real problem of substantial importance arises in regard to the best method of dealing with the associated questions of New Capital Expenditure and Depreciation (Renewals) of tractors, and a variety of methods of dealing with this present themselves and have been examined. The problem is one which is complicated by the variations between existing railway practice and theoretically correct accounting. From the different methods, each of which can be defended, we have chosen what we believe to be the soundest on broad general considerations. On the initiation of a general Electrification programme the provision of new steam locomotives would cease to be necessary, and the sums which would normally be required for this purpose can properly be regarded as a credit against the cost of the new Electric tractors. On the basis of information supplied by

the Railway Companies it appears that, taking the extreme case of an assumed life of 40 years and the maintenance of the existing average age, a sum of £42,200,000 must normally be devoted to Steam locomotive renewal in the course of the next 20 years. If the electrification programme be assumed to cover this period this sum can be regarded as an available credit, as it would have to be expended by the Railways even if Steam traction were retained.

In addition to this there will be a number of part worn steam locomotives at the end of the 20 years, some of which might be saleable, but we have assumed scrap value only, which is estimated at £3,300,000, making a total credit of £45,500,000.

(11) *Coal Stocks.*—The normal stock of coal held by the Railways is valued at about £1,380,000, and on electrification this can be used up without replacement, affording a corresponding credit to the electrification estimate.

(12) *Spare parts.*—The stock of steam locomotive spare parts can be used up without replacement. The value is estimated at £4,500,000.

Various Items.

(13) Some 27,000 wagons are at present employed on hauling locomotive coal. Assuming that 7,000 of these are still required for the (revenue earning) haulage of additional coal to the power stations supplying the railway load, the remaining 20,000 will become surplus and can be used for other revenue earning traffic, or their renewal can be avoided. The credit for these is estimated at £2,400,000.

(14) In the course of the L.N.E. investigation it was found that an appreciable saving of passenger coaches could be effected by the acceleration of services. Applying this in proportion to the whole country some 2,800 coaches could be released and used for replacement, to meet the increased Suburban train services, or their renewal could be avoided. The value of this credit is estimated at £2,500,000.

(15) The same investigation showed that a considerable quantity of plant, machinery and permanent way in workshops, sheds, etc., would become surplus and could, in some cases, be used elsewhere, or in other cases the cost of renewal would be saved. The credit for this is estimated at £4,000,000.

(16) On multiple unit equipments, which would be extensively used on short and medium distance passenger services, the carriage lighting would be supplied from the overhead wire, and the dynamos, batteries, etc., of the existing train lighting sets would be available for other stock, or if approaching their term of life, they would not require renewal. A credit of £2,000,000 is estimated on this item on the basis of the data given by the detailed investigations, and assuming that in 20 years' time all stock will be lit electrically.

In connection with all the above credits it is important to realise that the credit may arise in two different ways. If the item in question is almost worn out, it would have to be renewed under steam working, but under electrification this cost of renewal would be avoided. If the item has still a considerable useful life, it can be utilised elsewhere and a credit is therefore due for its part worn value. Having regard to the ease of transference of most of the items, and the 20 years' duration of the electrification programme, there seems no doubt that these credits should be fully realisable.

A number of other items would be rendered surplus such as land and buildings, water supply equipment, etc., but the possibilities of financial realisation of these are uncertain and no credit has been assumed for them, although some at least could be utilised in other ways or sold, and expenditure on the renewal of others could be avoided.

(17) In addition to this total of £261 millions on works and equipment of the Railways themselves, it would be necessary to provide additional generating plant, primary and secondary transmission lines and substations, the cost of which, under the arrangements contemplated, would be met by the Central Electricity Board and authorised undertakers. As the economic return on these works is covered by the estimated price per unit, it was not necessary for us to investigate in detail the capital expenditure involved; but to give a complete picture of the total expenditure, a figure of approximately £80 millions may be estimated for these items.

(18) It should be noted that in this estimate of capital expenditure allowance has been made for the electrification of every mile of track and railway owned siding in the country which is not already electrified. Obviously in practice this would not be done. Lightly loaded lines would be dealt with by the retention of steam haulage, or possibly by the use of oil driven coaches, and a reduction in the estimated capital expenditure would be secured without a proportional decrease in the savings in operation. On the other hand nothing has been included for the electrification of private sidings, and undoubtedly some considerable expenditure would have to be incurred under this head if satisfactory transfer arrangements are to be maintained.

TABLE II.

ESTIMATE OF COMPARATIVE WORKING COSTS, STEAM AND ELECTRIC.

(Including only items affected by electrification.)

	Steam. £	*Electric.* £	*Saving.* £
1. Locomotive fuel or electrical energy...	12,310,446	11,280,000	1,030,446
2. Locomotive wages	20,933,425	10,778,712	10,154,713
3. Repairs of Tractors	10,819,012	4.660,000	6,159,012
4. Water for Locomotives	883,666	—	883,666
5. Stores, Clothing and Miscellaneous	905,992	453,000	452,992
6. Lubrication	290,415	102,000	188,415
7. Maintenance of engine sheds and shops	436,959	175,000	261,959
8. Guards wages	4,296,462	3,653,462	643,000
9. Cleansing of vehicles	933,500	700,100	233,400
10. Insurance, Pensions, etc.	794,250	397,150	397,100
11. Savings on Maintenance of Train Lighting Sets ...	—	—	513,000
12. Savings on Auxiliary Power and Light Supplies ...	—	—	840,000
Totals	£52,604,127	32,199,424	21,757,703
Additional Costs of Electrification :—			
13. Maintenance and Renewals of Electric Track Equipment.		3,385,000	
14. Maintenance and Operation of Sub-Stations ...		1,056,000	
15. Increase in Depreciation (Renewals) of Electric Tractors compared with Steam.		20,000	
Total		£4,461,000	
Gross Savings due to Electrification	21,757,703		
Deduct extra costs of Electrification	4,461,000		
Net Saving due to Electrification	17,296,703		
16. Additional net Revenue on Haulage of Coal to Power Stations.	254,000		
	£17,550,703	= 6·7% on £261,000,000.	

NOTES ON ITEMS OF WORKING COSTS ESTIMATE (TABLE II).

(*Figures of Steam costs are extracted from the Ministry of Transport returns for* 1929 *unless otherwise stated. The Capital Credit, Item* 10, *Table I, having been calculated on a basis of maintaining the existing average age of steam locomotives, it is assumed that the steam operating costs would not vary to a material extent, and that the* 1929 *figures may be utilised for comparative purposes.*)

(1) *Locomotive Fuel.*—Total cost of fuel + 5 per cent. for cost of carriage on own railway.

Electrical Energy.—Estimated 114,000 million trailing ton miles at 50 watt hours per trailing ton mile, measured at the Direct Current busbars of substations, at 0.475 penny per unit.

No complete data are available as to total Ton Miles. The estimated figure of 114,000 million is based on such data as are available.

A rise or fall of 1*s*. per ton in the price of coal would increase or decrease the saving due to electrification by about £430,000 per annum.

(2) *Locomotive Wages.*—As a result of the detailed L. & N.E.R. investigation it was calculated that a saving of 53 per cent. would be effected in locomotive and shed wages and supervision. This allows for one driver only on multiple unit trains, shunting engines, and goods trains, but for a driver and assistant on locomotive hauled long distance passenger trains. The saving is due partly to this and partly to the great reduction in time spent on locomotive duties and to the acceleration of the slower trains. A saving of 50 per cent. has been assumed on wages and 10 per cent. on superintendence.

(3) *Repairs of Tractors.*—The total cost of steam locomotive repairs (excluding renewals) has been increased by £450,000 for share of superintendence. The savings on electrification are estimated at 57 per cent.

(4) *Water for Locomotives.*—This item will be eliminated.

(5) *Stores, Clothing and Miscellaneous.*—Estimated saving, 50 per cent.

(6) *Lubrication.*—A saving of 65 per cent. is estimated.

(7) *Maintenance of Engine Sheds and Locomotive Workshops.*—60 per cent. saving estimated.

(8) *Guards' Wages.*—Due to acceleration of slower trains and other causes a saving of 17 per cent. was calculated on the detailed L. & N.E. investigation. For this general estimate 15 per cent. saving has been taken, after reducing the " steam " total to allow for existing electric working.

(9) *Cleansing of Vehicles.*—A saving of 25 per cent. is estimated in view of the abolition of smoke and steam.

(10) *National Insurance, Pensions, etc.*—Roughly in proportion to the saving in wages.

(11) *Maintenance of Train Lighting Sets.*—These will not be required in multiple unit stock and the saving is based on that calculated in the detailed L. & N.E.R. investigation.

(12) *Auxiliary Power and Lighting Supplies.*—The saving on this is based on that estimated in the L. & N.E.R. investigation and the estimate is thought to be a conservative one. The saving would not only consist in replacing existing electric supplies by a cheaper supply, but also in very many cases the availability of cheap electricity would justify replacement of other forms of gas or oil lighting and power, with substantial economy and improvement.

(13) *Maintenance and Renewals of Electric Track Equipment.*—£50 per track mile per annum as an average for both running lines and sidings has been estimated for maintenance, and to this has been added provision for renewals, on an assumed life of 50 years for most of the items.

(14) *Maintenance and Operation of Substations.*—Assuming about 800 substations at an average annual cost of £1,200 each for operation and maintenance plus 10 per cent. for contingencies. Many would no doubt be automatically controlled and their cost should be much below this average figure.

(15) *Depreciation of Tractors (Renewals).*—The steam figure is taken at £2.53 millions for an estimated renewal cost of £84.4 millions with an assumed life of $33\frac{1}{3}$ years; the electric figure £3.7 millions is similarly based on estimated initial cost less scrap value, and the same life. On the completion of the electrification programme it will not be necessary to commence provision for renewals of electric tractors until these have reached an average age of half their normal life, i.e. for a period of about $7\frac{1}{2}$ years. If the electric provision of £3.7 millions be discounted back for this period, the regular annual provision commencing in the 21st year becomes £2.55 millions. The excess of this figure over the steam figure quoted above is £20,000.

(16) *Additional Revenue from Coal hauled to Power Stations.*—It is estimated that of the additional coal required by the power stations to deal with the Railway load about 2,800,000 tons will be rail borne, and that the additional net revenue therefrom will be about £254,000.

(17) *Local Rates.*—In view of the proviso attached by the Central Electricity Board to the estimated cost of electrical energy, we have endeavoured to ascertain the financial bearing of local rates on our estimates.

As regards the substations, assuming these are erected and owned by the Central Board and maintained and operated by the Railways, the rental being in substance included in the price per unit, we understand that if the railway companies are in " rateable occupation " of the substations, the latter would be held to be within the " cumulo " value of each Railway undertaking as a whole. It would appear that, assuming the most unfavourable case, the additional rates would not amount to a figure which would affect materially the estimated savings, and we have therefore disregarded this point.

We are advised that capital expenditure on electric track equipment or electric tractors is not likely to increase the rateable value, except in so far as electrification results in an increase in the average net receipts.

Further Considerations.

45. Having regard to the foregoing estimates, both detailed and general, we think it may reasonably be anticipated that, assuming general electrification on a 20 years programme, and assuming that existing traffics are maintained, there would be a surplus of approximately 2 per cent. available after meeting interest charges on the new capital involved. This is the crudest and most unimaginative expression of the economic situation.

Such a return taken by itself would not appear from a business point of view to warrant the adoption of a scheme of such exceptional magnitude. The margin would, in our view, be too narrow for the risks and contingencies involved.

This statement of the case is however incomplete. In the case of a change of this magnitude, the elements which do not lend themselves to direct monetary assessment are of great importance and must not be left out of account.

We have already indicated that electrification will enable the Railway Companies to offer the public a speedier and more satisfactory service than is possible under conditions of steam haulage. The effect of this improvement cannot be put into terms of cash, but should nevertheless be of considerable value, particularly under the present conditions of strenuous competition with rival forms of transport. Considerations of an analogous kind have undoubtedly weighed heavily in favour of the general improvements which the railways have carried out in the past, whether in increasing the comfort of passenger travel or in expediting the transport of goods traffic.

In our analysis we have taken as a basis the existing traffic which is being hauled to-day by steam. Any additional traffic carried in the future, either owing to improved service on the railway or through the general development of our country, its agriculture, and its industry, may be expected, by increasing the volume of traffic, to secure for the railways increased savings as compared with steam. Diagram I, Appendix II, shows the nature of these savings and indicates that, having regard to the heavy fixed charges involved, any increase in the volume of traffic tends, other things being equal, to increase the relative economy of electrification.

46. This consideration is of especial importance in connection with suburban traffic, and this is the second factor to which we think attention should be drawn. It cannot be doubted that such traffic is susceptible of substantial increase in volume and revenue under conditions of electric haulage, provided an interval service of sufficient intensity is established. There are many suburban areas, both metropolitan and provincial, where electrification has not yet taken place, and where such benefits could be realised, if suitable services are provided as part of a general scheme of main line electrification.

We have not felt ourselves able to include any allowance under this head in our estimate, but the possible financial benefits are substantial and we have endeavoured to assess them on very general lines as affecting all areas throughout the country, wherever it seemed probable that traffic would respond adequately to an intensification of the service.

The results of our consideration of this subject are given in Appendix III. They cannot be taken as more than a very rough approximation, and this is particularly the case with our endeavour to estimate the additional capital expenditure involved. Many of the lines round our large cities are congested with long distance passenger trains and with freight services of all descriptions; to establish an intensified suburban service in such cases involves heavy expenditure on the provision of additional tracks, on the re-construction of passenger stations, and on the re-modelling of signal equipment. No reliable estimate of the cost involved can be made without detailed investigation which it is impossible for us to undertake. On such material as we have had available we have estimated the additional capital expenditure involved at £45 millions, and the additional net revenue at £5.85 millions or a return of 13 per cent. In giving these figures we wish to emphasize that the scheme to which they have reference is not one of independent suburban electrification, but a scheme of general suburban intensification superimposed on a scheme of general electrification.

We have treated the question of intensive suburban electrification as a secondary factor in the problem which we are called upon to consider, although we have little doubt that it would be the most remunerative portion of a general electrification scheme. The estimates of additional expenditure on, and revenue from, suburban schemes are, as we have stated, necessarily on even broader lines than those of the general estimate. Any more conclusive figures would have entailed a very lengthy period of investigation of the potentialities of the various areas concerned.

We would note here that it has been suggested that the economic method of carrying out a general programme of railway electrification would be to electrify all suburban areas in the first place, subsequently linking up the main lines between. The suggestion is attractive at first sight, but in our opinion it should be treated with caution, as it seems probable that in many cases the handicap of dual working, to which we have already drawn attention, might substantially affect the financial return due to increased suburban traffic.

47. There is further the somewhat contentious factor of increased revenue on main lines through the ability of an electrified system to give to the public a better transport service. Apart from suburban services, it seems probable that electric traction would be the means of attracting additional traffic to the railways in a number of different directions. We have not thought it advisable to speculate upon any acceleration of the speed of the principal express services, but undoubtedly electric traction renders possible a considerable acceleration of the intermediate and stopping services, and such acceleration would be a powerful factor in favour of the railways in competition with road traction.

The adoption of electric traction generally would afford to the Railway Companies the opportunity of intensifying their main line and inter-urban services on more economic terms than are open to them under conditions of steam traction. Small multiple unit sets could be worked more cheaply than steam trains, and, where traffic conditions permit, could be run at regular intervals between the principal express services. In certain cases

a multiple unit service run at frequent intervals might replace completely an existing locomotive-hauled service run at wider intervals. It must be borne in mind, however, that the institution of a more frequent service of this kind on busy main lines is very largely dependent upon the demands made for other descriptions of service.

Subject, however, to this limitation, it may be anticipated that such interval services, where it is found possible to run them, will lead to an increase in traffic which will more than cover the cost of the additional train mileage. We take the view that this will particularly be the case between large towns at moderate distances, where traffic conditions permit. It is doubtful, however, whether a more frequent service would contribute materially to an increase of travel between points at a greater distance, e.g., London-Newcastle or London-Glasgow. In these cases it is hardly to be expected that a more frequent service would develop the traffic sufficiently to cover the additional expense, though there is at least a speculative possibility that with a cheap electric unit this may prove to be the case.

The possibility of increased net revenue resulting from an intensified service between large towns within, say, 100 miles of one another, is one which should be kept in mind as a possible direct advantage of the adoption of electric haulage, but it is not possible for us to make any estimate of the additional sum which might be realised.

Electrification, as we have previously indicated, places in the hands of a traffic manager a new machine or system which enables him to offer a more attractive transport proposition to his public, and whose special characteristics are capable of extensive development.

48. Finally, account should be taken of a number of advantages, several of which would, in our opinion, prove to be of definite financial benefit, but which we have left out of consideration in our main estimate, as being factors which it is impossible to assess with any accuracy. However, we think it prudent to draw attention to the very substantial additional saving which would be secured through electrification in the event of any increase in the basic prices of coal.

Risks and Contingencies.

49. Having now dealt with certain important considerations which would tend to modify the financial result in a favourable direction, we think we should fail in our duty if we did not give attention to the risks and contingencies involved in arriving at any conclusions based on estimates.

There are certain directions in which our estimates, though framed on the most conservative lines and on the advice of the best technical experts, may prove erroneous, having regard to the unprecedented magnitude and character of the scheme under investigation, namely, the progressive electrification of 20,000 miles of a most intensively worked railway system.

Firstly our estimate of the capital cost of the whole work may prove inadequate. We have examined in detail two considerable sections of line, and we believe that these may be taken as reasonably typical of the country as a whole. On a more detailed examination this may prove incorrect, and the error may be such as to affect materially the estimate of the first cost of the scheme, in either direction.

Next, our estimate of the savings to be effected under the scheme has been based in the main on a detailed examination of the results to be expected from two sectional schemes. The main items of savings are in locomotive maintenance and wages of trainmen. The first item can, we think, be regarded with reasonable confidence. The other must depend on an estimate of the utilisation of tractors and stock under British main line traffic conditions and may prove excessive.

Further, it has been impossible for us to examine in any detail the question of costs of operation during the progress of the scheme of electrification, estimated to last over a period of 20 years. During this period there will necessarily be an intermixture of steam and electric haulage with some duplication of expenditure, which will not wholly disappear until the completion of the entire programme. The result of the detailed inquiry into the section Crewe to Carlisle showed how small may be the saving with dual working on a congested system of lines such as is to be found in many parts of this country, and it is difficult to estimate how far such dual working could be minimised during the carrying out of the whole programme.

This difficulty, and others of a kindred nature which may arise in carrying out an extensive programme, will have the effect of postponing for a longer or shorter period the attainment of the full return on the capital expended. We must point out that the picture of comparative costs of operation shown in para. 44 represents the position in the 21st year when electrification is complete. During the transition period of 20 years, such calculations as we have been able to make appear to show that although the full saving will not be realised at once, the return obtained from electrification should cover the temporary costs of dual working and meet the interest charges averaged over the whole programme.

Put shortly, the risks involved in undertaking a comprehensive programme cannot be predicted with accuracy. They lie in the fallibility of estimates, in the possibilities of reduction in traffic due to further development of road transport, or to reduced national activity, and finally, in the field of speculative scientific development.

Effect on Railway Staff.

50. The estimated reductions in locomotive wage costs constitute the principal item in the savings to be effected under electrification. The effect of a comprehensive electrification programme extending over a period of twenty years on the men serving in the grades mostly concerned, i.e. drivers, firemen and cleaners, is a matter which will call for careful examination. We have not felt that it was possible at this stage to give the matter the detailed consideration which it will undoubtedly require before any final conclusion is arrived at. Such consideration as we have given, however, leads us to the view that there will be no serious adverse effects on the men now occupying these grades, particularly having regard to the fact that any scheme of electrification will include a considerable intensification of suburban services and will be favourable to the establishment of additional train mileage in areas other than suburban. Apart from this, the physical conditions under which motormen and other traction staff will be called upon to work under electrification will be substantially more favourable than the present.

Effect on National Coal Output.

51. The total consumption of coal on steam locomotives in Britain during 1929 was approximately 13,400,000 tons, which is about 5.2 per cent. of the total tonnage of coal raised in the year (258 million tons).

In the event of electrification, allowing for an estimated consumption in 1950 of 1.43 lbs. of coal per K.W.H. (Sub-station output), the total required for the railway load would be about 3,650,000 tons, so that the net reduction in coal consumption attributable to railway transport would be about 9,750,000 tons or 3.8 per cent. of the national output.

Effect on Industry.

52. In view of the magnitude of a comprehensive scheme of railway electrification such as we have indicated, it appeared essential to investigate to some degree the ability of the British electrical manufacturing industry to meet the demand for the electrical apparatus involved, and the reactions, if any, on existing suppliers of steam haulage units. In this investigation we were assisted by the four large British electrical manufacturing companies who contributed a joint memorandum and who collaborated in preparing evidence given by Sir Philip Nash on their behalf. This evidence was primarily concerned with the supply of traction units.

The British manufacturing industry appears to have carried out important contracts for railway electrification in various parts of the world, on a variety of systems covering a complete range of voltages and types; this has involved a large number of designs to suit different conditions and gauges, and has resulted in the accumulation of engineering knowledge, development, and experience in this country, which is therefore available for British railways if electrification schemes are adopted.

In addition to the actual experience possessed by the British companies, arrangements exist between them and the most prominent manufacturers in the United States and in Europe under which technical information is exchanged, and thus the British knowledge is supplemented by the experience of others. The satisfactory results which have been obtained on the electrified systems where the work has been carried out by British firms indicates a high degree of technical skill and knowledge of the requirements which may be met with in work of this nature, and the fact that this work has been obtained in the face of world-wide competition is proof of the ability of British manufacturers to produce the necessary equipment of high efficiency at competitive prices.

Accordingly we conclude that on the score of technical and manufacturing experience the industry is well fitted to undertake the task.

53. In regard to manufacturing capacity, we are informed that the facilities available for dealing with the electrical equipment of locomotives and multiple unit stock for main line electrification are greatly in excess of any demand which has hitherto arisen, and it is estimated that a complete electrification of British railways could be undertaken with the existing facilities if the work was spread over a period of fifteen years. In the past the demand for this class of equipment has fluctuated widely, and if a comprehensive scheme were adopted it would be of the utmost importance to arrange that there would be a steady load on the various factories for a definite period of time. This would enable the manufacture to be carried out on the most economic basis, thereby ensuring a minimum price to the railway. In addition, there would be the great advantage that the workers employed on this class of material would have steady employment, and they would not be subject to dismissal when particular contracts are finished as is the case at present. The importance of having a body of skilled workpeople continuously employed cannot be over-estimated.

In regard to the cable making and wire drawing industries, on which large demands would be made, we are authoritatively informed that no difficulties would be met with in supplying the full needs, in the main from existing available facilities.

While the substitution of electric for steam tractors in the United Kingdom must of necessity cause a reduction in the utilisation of that portion of the existing equipment of steam locomotive builders which is now devoted to home requirements, and of the railways

own constructional shops, it is obvious that the existing plant of such manufacturers and of the railways can and should be utilised to provide all the mechanical parts of the electric tractors which will be required; and it would therefore be neither necessary nor economical for electric manufacturers to undertake the production of the mechanical parts. The capacity of existing manufacturers to provide these mechanical parts is of course undoubted.

54. In connection with this aspect of the problem we have been impressed with the necessity and importance of simplification and standardisation throughout the technical programme. It appears to us that an essential part of any comprehensive scheme should be the adoption of a single technical policy common to all the railway groups. If the railway companies could in their collective capacity formulate their requirements on the basis of the adoption of as few types of tractor as possible, we are informed that the manufacturers would be prepared to pool their resources in designs, patents, and productive capacity with a view to producing the necessary electrical equipment of the most suitable design, and in doing so to attain such standardisation as will make possible the fullest measure of interchangeability.

We have dwelt on the manufacturing aspect of the general problem for the following important reason. In the estimates of capital expenditure prepared by our advisers, particularly as regards tractors, the prices taken have been those of to-day. On the other hand, on the basis of a comprehensive programme involving the production of standardised units, it is clear that very substantial reductions on such prices could be secured. The savings effected through a steady flow of work over a long period, not only on overhead charges but also on actual works cost might, in our view, be as high as 10 to 15 per cent., and this possibility should be borne in mind in relation to the estimate which we have put forward.

55. It is of national importance to note that with the exception of the imported raw material, mainly copper involved in the cables, etc., substantially all the expenditure under a comprehensive programme would be distributed in this country ultimately in the form of wages. Assuming a capital expenditure of £261 millions by the Railways and £80 millions by the Central Electricity Board and other authorities concerned, the estimated employment given to British labour would represent over 60,000 men per annum over a period of 20 years. (This is on the basis commonly accepted that £1 million provides work for one year for 4.000 men, and after making a deduction for a comparatively high proportion of imported raw material.)

While it is the case that a substantial part of this would be spent in the electrical industry, which at present has perhaps the smallest degree of unemployment in the British Engineering world, a very considerable part would go to the iron and steel, structural and building industries, and to industries ancillary to the electrical industry. In the electrical industry itself, the expenditure under the programme would lead to the absorption of men at present unemployed in general engineering and of the machinist or semi-skilled class.

Further, it is clear that any programme of this nature would greatly increase the power of British electrical manufacturers to compete in the world's market due to the steady nucleus of work over which to spread their standing charges.

PART III.

Summary and Conclusions.

(References are to paragraph numbers.)

We are not asked in our terms of reference to embody in our Report any definite recommendations, but, as a final result of the foregoing, we have come to certain unanimous conclusions of major importance which we now summarise.

(i) The existence of the national scheme of generation of electrical energy and the consequent low price and availability of such energy constitute a new and favourable factor in the economics of further railway electrification in Great Britain. (4).

(ii) An efficient and progressive railway system is and will continue to be a matter of vital importance to the Nation. (6 and 7).

(iii) In view of the competition of road transport and the existing industrial and agricultural depression, it is essential that the railways should examine new methods of reducing the costs of railway transportation. (7).

(iv) Comprehensive electrification of main line railways has not taken place in any foreign country except Switzerland, but generally speaking railway electrification is making steady progress in many parts of the world. (10-16).

(v) The main reasons which have led to the adoption of electric haulage in foreign countries, broadly speaking, do not apply in this country, and they have not offered any conclusive guide or assistance in our investigations. (17).

(vi) British railway electrification up to now has been confined to suburban lines, and the results, economic and otherwise, have been favourable. (18).

(vii) The economic success of British suburban electrification is due to the substantial increase in revenue following on the much improved service which an electrified railway can provide. (18).

(viii) Suburban electrification provides no sound comparison of actual operating costs of steam and electric haulage, but it does present certain *prima facie* considerations in favour of electric haulage for main lines. (19-21).

(ix) The increased load on the national system which electrification of the railways would contribute, together with its high load factor, would react most favourably on the cost of electrical energy produced for all purposes, while the additional transmission network required for railway electrification would do much to accelerate rural electrification throughout the country. (24).

(x) In the event of a scheme of main line electrification being adopted, the Central Electricity Board should be given statutory power to supply electrical energy direct to the railways for electrification schemes. In addition to this railway companies should be entitled to utilise, for purely railway purposes, at any point in their systems, supplies of electrical energy obtained from the Board or any other authorised undertakers. (25).

(xi) In any comprehensive scheme of railway electrification the Central Electricity Board should provide the transmission lines, build and equip the sub-stations, and supply the energy at the Direct Current bus bars of the sub-station, but the operation and control of the sub-stations should be in the hands of the railway companies. (26).

(xii) In regard to the most suitable system of electrification, the report and recommendations of the Pringle Committee should be followed. (28).

(xiii) Improvements in the fuel economy of steam tractors will take place, but such economy is likely to be counterbalanced by higher capital costs and maintenance charges. (30).

(xiv) The most promising alternative to steam haulage, other than electrification, rests in the development of the oil engine with electrical transmission to the driving wheels, but experience of this system is still limited, and it would appear that on well-loaded lines this system must always be less economical than electrification. (30).

(xv) In considering alternatives to the steam locomotive preference should be given to systems using coal rather than oil as being in the national interest. (30).

(xvi) Apart from the direct financial economies of electrification as disclosed in comparative costs of operation, electrification offers important indirect advantages associated with speed, comfort, amenity, improved service, and increase of capacity. (33).

(xvii) Leaving aside the financial aspects of the matter, the disadvantages of electrification relate almost entirely to the dependence of the system on centralised sources of electrical energy. (34).

(xviii) The main items of haulage cost which can be materially reduced by electrification are locomotive wages and locomotive repairs. (36).

(xix) Unless special conditions obtain, the electrification of small sections of a main line railway system is unlikely to be economically justified on account of the costs of dual working, and the consequent inability to take the fullest advantage of the new capital expended on fixed equipment or haulage units. (42).

(xx) To secure the fullest economic advantage of railway electrification in this country, any scheme adopted should be a comprehensive one preferably comprising all the non-electrified lines, less such branch lines as detailed examination may show to be more economically operated by independent haulage units either steam or oil electric. (42).

(xxi) Assuming that such a scheme is carried out on a comprehensive programme over a period of from 15 to 20 years, on a conservative basis and on the assumption of existing traffic, the new capital involved on the part of the Railways would be approximately £261,000,000, and the return on this through the various economies would represent about 7 per cent. (44).

(xxii) Apart from the direct return due to these economies other substantial advantages could be realised, the most important being increased revenue from suburban and inter-urban traffic. On a broad estimate we anticipate that schemes of intensifying suburban working would yield an additional revenue of £5,850,000 representing a return of 13 per cent. on the additional capital expenditure of £45,000,000 which would be involved. (46).

(xxiii) The figure of estimated capital expenditure is likely to be reduced due to non-electrification of lightly loaded lines, redundant lines, and sidings, and reduction in capital cost of tractors, etc., due to large scale production, and a continuous manufacturing programme. On the other hand some allowance must be made for the electrification of private sidings and private branch railways worked over by the railway companies in the process of the transfer of traffic. (44).

(xxiv) In addition to the expenditure under this programme, there would be a further expenditure by the Central Electricity Board and authorised Undertakers of approximately £80,000,000 in excess of existing programmes, on which these bodies would earn their normal revenue. (44).

(xxv) The change over from steam to electric traction will not materially affect the conditions of railway employees other than those in the locomotive grades. Even in the case of these grades we anticipate the adverse effect of the change will be of a limited and temporary character owing to the duration of the programme, together with the probable increase in suburban and other train mileage. The matter, however, is one which should be more closely examined if it should be decided to proceed with the scheme. (50).

(xxvi) Apart from considerations of finance and railway administration, a comprehensive programme such as we have indicated, if it is to be undertaken, should preferably be carried out as a united co-operative scheme by the railway companies, in order to obtain the best results from the technical, construction and supply standpoint. (54).

(xxvii) From the point of view of technical development and international competition the value of such a programme of domestic electrification would be most substantial to our national electric manufacturing industry. (55).

General.

The preceding are the conclusions we have formed, and we would bring our report to an end with one general observation. The existing railway system is a vital part of the equipment of our country and its efficiency and economy affect the lives of practically every inhabitant, our industry and our agriculture. A definite decision to alter the haulage system on a comprehensive programme, which in our view is the only method of achieving complete success, would involve a commitment of capital expenditure by the railways of about £261 millions, and of about £80 millions by the Central Electricity Board and other authorities, apart from the extra expenditure necessary in order to realise an intensive suburban development. The magnitude of this would be unique in the history of world enterprise.

On the other hand, we feel bound to point out that without any predetermined long term programme, our national expenditure on the construction, improvement and maintenance of roads in the last ten years has probably amounted to the colossal sum of £500 millions and is now proceeding at the rate of over £60 millions per annum. Road haulage is in direct competition with the Railways for a large amount of traffic but, unlike the railway system, there exists for the roads no balance sheet or computation of profit and loss. There is no definite economic test of financial soundness. With this reflection in mind, we have no hesitation in concluding that the mere magnitude of the sum involved in complete electrification of our railways should be no deterrent in itself to the most careful and earnest consideration of such a programme on its economic and social merits. The decision involves national, financial and possibly ultimate political considerations and implications which we do not feel it is any part of our present duty to discuss, but we trust that towards the consideration of the problem which will no doubt take place in the minds of those concerned, the railways, the Government and the country, we have at least made clear the essential economic factors.

From no mere precedent or tradition do we pay our tribute to our Secretary, Colonel Trench, who has been indefatigable in the interests of thoroughness, invaluable as regards the technical aspect and happy in his unfailing courtesy, and to whom we extend our united thanks and appreciation.

We have the honour to be,
Sir,
Your obedient Servants,
WEIR, *Chairman.*
R. L. WEDGWOOD.
WILLIAM McLINTOCK.

A. C. TRENCH, *Secretary.*

24th March, 1931.

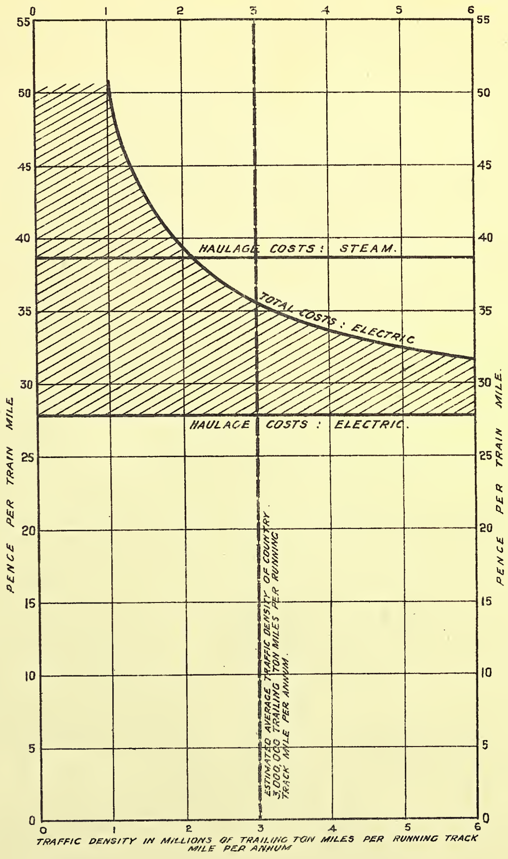
APPENDIX 1.

LIST OF WITNESSES.

Sir John Aspinall.
Sir Philip Dawson, M.P.
Sir Andrew Duncan.
Sir Henry Fowler, K.B.E.
Mr. H. N. Gresley, C.B.E.
Sir Brodie Henderson, K.C.M.G., C.B.
Mr. Frank Hunt, C.V.O.
Mr. Herbert Jones.
Mr. J. M. Kennedy.
Mr. F. Lydall.
Mr. C. H. Merz.
Mr. J. Milne, C.S.I.
Sir Philip Nash, K.C.M.G., C.B.
Mr. H. W. H. Richards.
Mr. C. E. R. Sherrington, M.C.
Mr. Roger Smith.
Sir John Snell, G.B.E.
Sir Josiah Stamp, G.B.E.
Sir Herbert Walker, K.C.B.

Diagram nº I *Appendix II*

CURVE SHOWING SPREADING OF ELECTRIFICATION FIXED CHARGES BY INCREASING TRAFFIC DENSITY



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APPENDIX II.

Traffic Density as affecting Electrification.

The important bearing which traffic density has upon the economics of Railway Electrification is indicated in Diagram I.

For the purpose of comparison with steam operation, the total cost of electric operation may be divided into two portions (a) haulage cost as described in para. 36, most of the items being less than the similar items for steam haulage, and varying almost directly with the number of train miles run, and (b) fixed charges, comprising interest, depreciation, maintenance and operation costs of the fixed equipment; within limits the cost of these is fixed per track mile and does not vary much whether the traffic be heavy or light.

It follows that with a dense traffic the fixed charges per track mile are divided among a larger number of trains, and the total cost of electric operation per train mile, i.e. haulage cost plus fixed charges, is reduced by an increase of traffic.

Diagram I, where the shaded area represents the fixed charges, indicates that for any traffic density above about 2.3 million trailing ton miles per running track mile per annum electrification should be profitable, and that the margin of profit increases with an increase of traffic.

The average traffic density of the railways of Great Britain is estimated at 3 million trailing ton miles per running track per annum. The elimination of lightly loaded branch lines etc. would of course increase the average density of the remainder. The average traffic density of the L.N.E.R. area investigated by Messrs. Merz and McLellan (see Map in Appendix IV) was found to be 4.3 million trailing ton miles per running track mile per annum.

Notes on Diagram I.

All costs are based on figures of Committee's estimates for General Electrification, para. 44, and on the assumptions made therein regarding supply of energy.

Haulage costs, steam and electric, include Items 1 to 10 of Table II (para. 44) with the addition of the full cost of renewals and interest on tractors. Cost of each train mile includes its proportion of shunting.

Fixed charges, electric, are estimated at £322 per running track mile per annum which figure includes interest, maintenance and renewals of electric track equipment, interest on alterations to way and works, and maintenance and operation of sub-stations. Charges on each running track mile include those on its proportion of siding track.

Haulage costs are calculated for 3,000,000 trailing ton miles (train ton miles plus shunting ton miles) per running track mile per annum, and assumed to be constant for other traffic densities. This is not strictly accurate but as the variable factors would have a generally similar effect on both steam and electric operation, they are disregarded for the purposes of this illustration.

Permanent way and similar items common to both systems are excluded.

Total train miles (1929) by steam traction, 373,000,000.

APPENDIX III.

Possibilities of Suburban Electrification.

Any scheme for the complete electrification of the railway system of this country would include the electrification of a considerable mileage of lines of a suburban character. On lines of this character passenger traffic readily responds to the stimulus of an intensified and accelerated service such as can be cheaply and readily provided under electric haulage. The additional revenue to be earned in this way would undoubtedly be substantial, and should be taken into account in any attempt to assess the secondary advantages of a general scheme of electrification.

Experience shows that, in order to secure and to cater for an additional volume of traffic, a heavier expenditure is necessary for suburban electrification as measured in cost per mile of track. Additional rolling stock must be purchased, car sheds and siding room provided, stations enlarged, and signalling modernised. Moreover extensive widenings and other alterations of running line accommodation are frequently found to be necessary. On the basis of some recent cases which may be taken as typical of London and provincial conditions this additional expenditure may be put at about £10,000 per track mile on the average. If the suburban track mileage of the country be taken as approximately 4,500 miles, we arrive at a total additional capital expenditure round about £45,000,000.

The intensification of the service also involves an increased operating expenditure which in the cases under notice amounted in round figures to £800 per track mile per annum. If these cases may be taken as typical, this item represents an addition of £3,600,000 to the current costs of suburban operation. Some allowance must also be made for the maintenance and renewal of additional tracks, bridges, signals, etc. This may be very roughly estimated at 1 per cent. on one-third of the total additional capital cost, or say £150,000 per annum.

To meet these extra annual costs and to remunerate the additional capital expended, one must look to the prospective growth in passenger traffic stimulated by an improved and intensified service. It is clearly a difficult matter to frame an estimate either as to increased volume of business or as to increased revenue. It may be anticipated that the growth of suburban traffic in the neighbourhood of provincial centres would not be so pronounced as it has proved to be in the neighbourhood of London. Allowance must also be made for the probable development of competing forms of transit, whether by road or by tube. An ultimate Revenue increase of 80 per cent. may perhaps be taken as a conservative estimate.

The revenue from suburban traffic as a whole, excluding areas already electrified, may be estimated as £12,000,000. An increase of 80 per cent. on this total would give an increased revenue of £9,600,000

Deduct.		
Additional operating expenses	3,600,000	
Maintenance and renewal of the additional Tracks, etc.	150,000	
		3,750,000
Balance		5,850,000

being a return of 13 per cent. on the additional capital of £45,000,000 as a contribution to strengthen the case for the complete scheme of electrification. There is inevitably a very large amount of conjecture involved in these figures, but on the whole the estimate may, we think, be taken as a reasonable anticipation of the return to be obtained from the additional capital expenditure involved.

APPENDIX IV.

REPORT BY MESSRS. MERZ AND McLELLAN ON THE ELECTRIFICATION OF A PORTION OF THE LONDON AND NORTH EASTERN RAILWAY.

TABLE OF CONTENTS.

LIST OF TABLES INCLUDED IN THE REPORT.

MAP OF ROUTES CONSIDERED.

July, 1930.

To

THE SECRETARY,

THE RAILWAY ELECTRIFICATION COMMITTEE.

SIR,

We now have pleasure in submitting herewith our report on the electrification of a portion of the London and North Eastern Railway, which we have investigated in accordance with the Committee's instructions. The scheme includes a section of the main line from London to Doncaster and Leeds, and several branch lines in Lincolnshire. The report sets out in detail the traffic on the various lines to be dealt with, the proposed methods of working the traffic electrically, estimates of Capital Outlay on electrification, comparative estimates of steam and electric operation, and the financial result deduced from this comparison.

Summarised very briefly, the figures are as follows:—

Total Route Mileage is about	500
Total single track mileage, including yards and sidings, about	1,950
Trailing ton miles, per annum, are about	6,000,000,000
and the Engine miles	21,000,000
The net Capital Outlay is about	£8,646,000

The saving in working expenses is £624,630, representing 7.22 per cent. on the net Capital Outlay.

This is subject to modification in the event of the price of coal rising or falling from the present level, the saving in the working expenses being increased or decreased for each rise or fall of 1*s*. per ton by £19,454, which is equivalent to 0.225 per cent. on the net capital outlay.

From this saving must be deducted the increase, if any, in the local rates payable by the Railway Company in respect of the electrical installation, including the substations, which, in the present circumstances, we have not attempted to estimate. The balance should be sufficient to pay the interest charges on the net Capital, with a small margin.

It will be noted that, as agreed with the Railway, no assumption has been made as to any increase in the traffic beyond that of last year. Further, although a large part of the passenger traffic and nearly all the goods traffic would be speeded up, no increase in the revenue consequent thereon has been assumed.

Although the statistics of mileage and traffic have been sub-divided under four sections, we have not attempted to sub-divide similarly the estimates of Capital Cost and Working Expenses. The traffic on the various sections is, to a certain extent, interdependent, and, if one or more sections were omitted from the complete scheme, fresh estimates would have to be prepared for the remaining sections. The figures contained in the Report shew that the traffic varies widely on the different lines. Thus, for example, although the London-Leeds section has only one-third of the total route mileage, and only one-half of the single track mileage, the traffic on this section, expressed in trailing ton miles, or engine miles per annum, is two-thirds of the total. The cost of the electrical installation, apart from locomotives, being approximately proportional to the single track mileage, it might appear that the electrification of this section alone would shew a better return on the capital expenditure than the complete scheme. As, however, the exclusion of any section might involve a reduction in the traffic on the remaining sections that could be profitably hauled electrically, it is impossible to say without a fresh investigation what would be the result of electrification of individual sections.

Much of the material necessary for such subdivision is available, and the separate estimates could without difficulty be worked out, but would take some time. For the present, we have confined our attention to the complete scheme in accordance with the Committee's instructions.

We trust that the Committee will find in this Report all the information which they require, but we are at their disposal to elucidate any points on which they would like further explanation.

Yours faithfully,

MERZ AND McLELLAN.

LONDON AND NORTH EASTERN RAILWAY.
REPORT ON ELECTRIFICATION.

In this report we give the results of our investigation into a scheme of electrification for a considerable section of the London and North Eastern Railway. The section, which is shewn in the map accompanying this Report, comprises the main line from King's Cross to Doncaster and Leeds, the branches from Grantham to Nottingham, Boston and Lincoln, the line from Doncaster to March viâ Lincoln, Sleaford and Spalding, the line from Peterborough to Grimsby and Cleethorpes viâ Boston, the Mablethorpe and Skegness branches, and the connecting line from Coningsby Junction to Bellwater Junction.

This group of lines has been selected with two objects in view. First, the Committee desired that the scheme investigated should be fairly representative of the British Railways as a whole, and not merely a scheme for electrification of a particular section on which, due either to very dense traffic or to the existence of steep gradients or long tunnels or to other local conditions, the conversion to electric working would present obvious advantages. Second, it was important to base all calculations on statistics as to traffic and working expenses which could be taken out from actual records without having to make more assumptions than was absolutely necessary to allow for the continued running of some of the traffic by steam and the retention of some running sheds, coaling plant, watering arrangements, etc., for the maintenance and operation of steam locomotives.

TABLE I.

Route and Single Track Mileages.

Section No.	Description.	Route Mileage.	Single track mileage.		Sidings clear of Running Lines.	Single Track Mileage.				
			Running Lines.	Sidings in Running Lines.		Traffic Sidings.	Traffic sidings at intermediate stations.	Traders sidings at all stations.	Loco. and Engineers sidings at all stations.	Section Totals.
1	King's Cross–Leeds, excluding lines already included under the Suburban Scheme from King's Cross to Welwyn Garden City				King's Cross...	22·39				
					Holloway ...	3·74				
					Finsbury Park	14·21				
					Harringay ...	17·10				
					Hornsey ...	9·61				
					Wood Green...	2·76				
					Hatfield ...	4·50				
					Knebworth & Langley ...	4·04				
		165·1*	644·8	22·3	Hitchin ...	5·53				
					Arlesley ...	2·33				
					Biggleswade...	3·81				
					Sandy ...	2·45				
					Huntingdon...	3·50				
					Fletton ...	1·95				
					Peterboro' & New England	36·55				
					Grantham ...	4·77				
					Newark ...	4·24				
					Retford ...	4·44				
					Doncaster ...	34·10				
					Wrenthorpe...	8·30				
					Ardsley ...	11·20				
						201·52	60·89	33·20	73·81	369·42
2	March–Doncaster ...				Lincoln ...	10·87				
		98·2	210·93	7·41	Whitemoor (5 reception roads only)...	2·11				
					Gainsborough	2·65				
						15·63	27·37	3·87	4·90	51·77
3	Grantham–Nottingham. Grantham–Lincoln–Boston ...				Colwick ...	46·27				
					Sleaford ...	3·29				
					Boston ...	17·20				
		73·7	160·88	6·57		66·76	19·20	10·61	3·27	99·84
4	Peterboro'–Grimsby–Cleethorpes and branches. Lincoln–Boston ...				Spalding ...	4·70				
					Cleethorpes ...	2·83				
					Skegness ...	5·19				
						12·72	48·31	6·57	·63	68·23
		155·0	296·10	6·63						
		492·0*	1312·71	42·91		296·63	155·77	54·25	82·61	589·26

* Not including King's Cross to Welwyn Garden City, a distance of 20·6 miles.

Both these objects have been fulfilled in the selection of lines dealt within this Report. The traffic between London and Doncaster is very heavy, whereas on several of the lines in Lincolnshire the traffic is very light. The sections included constitute the bulk of the old Great Northern Railway, and are still for most purposes worked as a self-contained group.

The maximum gradient on any part of the scheme is 1 in 80 on the Doncaster—Leeds section, but on the majority of the lines the gradients are easier than this. For example, on the main line between King's Cross and Doncaster, apart from short stretches of 1 in 100, the maximum gradient is 1 in 200.

We have been advised by the Railway as to the goods yards which, for traffic and other reasons, should be considered as forming a part of the Scheme, the most important being King's Cross and others in the London area, Peterborough, Colwick, Doncaster and Wrenthorpe and Ardsley in the Leeds area. Certain other yards adjacent to the section are omitted from the Scheme. An example of this is Whitemoor, where half of the reception roads only have been included.

In accordance with our instructions we have assumed that the suburban services from King's Cross to Welwyn Garden City have already been electrified, and that no provision need be included in the present scheme for working this traffic or for the equipment of the lines or for the power supply arrangements necessary for the suburban scheme. We have therefore only allowed in our estimates for the equipment of those tracks in the London area which are not required for suburban working, and for the additional plant in the substations necessary for the main line traffic and the work in the goods yards.

The route and single track mileages are given in Table I.

Traffic Statistics.

For the compilation of the traffic statistics on which the comparison of steam and electric operation has been worked out, particulars of all trains were taken out from the records for certain weeks in the year 1929, which were selected by the Railway Officers as being typical of the conditions at different seasons. From the figures so obtained the totals for the year were compiled. The statistics are set out in Table II.

TABLE II.

TRAFFIC STATISTICS.

Summary of Trailing Ton Mileages.

Section.	London–Leeds (excluding Suburban Traffic as far as Welwyn Garden City).	Doncaster–March.	Grantham–Nottingham and Grantham–Lincoln and Boston.	Peterboro', Grimsby and Cleethorpes Skegness branch, Mablethorpe Loop, Lincoln–Boston, Coningsby–Bellwater.	Total.
STEAM.					
PASSENGER.					
Loaded	1,440,461,815	116,286,021	84,048,366	175,480,058	1,816,276,260
Empty	51,454,505	3,488,580	2,521,452	5,264,401	62,728,938
Shunting by train engine ...	1,820,850	360,350	611,800	2,428,100	5,221,100
Total	1,493,737,170	120,134,951	87,181,618	183,172,559	1,884,226,298
GOODS.					
Loaded and Empty ...	2,302,959,581	900,825,887	336,858,938	287,061,164	3,827,705,570
Shunting by train engine ...	25,724,852	6,909,722	3,624,708	6,761,125	43,020,407
Total	2,328,684,433	907,735,609	340,483,646	293,822,289	3,870,725,977
SHUNTING BY SHUNTING ENGINES.					
Passenger	28,396,350	980,200	237,300	353,450	29,967,300
Goods	107,992,778	13,235,554	19,917,688	14,361,044	155,507,064
Total	136,389,128	14,215,754	20,154,988	14,714,494	185,474,364
SHED SHUNTING	64,748,250	15,518,850	4,554,300	4,559,400	89,380,800
BALLASTING	14,479,761	2,618,300	2,022,897	2,534,442	21,655,400
DEPARTMENTAL	8,508,550	449,550	849,150	632,600	10,439,850
Total	4,046,547,292	1,060,673,014	455,246,599	499,435,784	6,061,902,689
ELECTRIC.					
All figures except "Shed Shunting" as above.					
SHED SHUNTING	6,474,825	1,551,885	455,430	455,940	8,938,080
Total	3,988,273,867	1,046,706,049	451,147,729	495,332,324	5,981,459,969

Traffic Working.

In general, passenger trains may be worked electrically in two alternative ways, viz., by locomotive-hauled trains and by multiple-unit trains consisting of self-propelled or motor coaches and trailers. There are advantages in each method. Where trains have to run for long distances at high speeds (up to 75 and 80 miles per hour on British railways), and may have to run over sections where electric working is not in force, it is advantageous, if not actually necessary, to use locomotives. There are, however, on all sections a number of passenger trains which stop frequently and have only a limited length of run, and for such trains the multiple-unit system is well adapted by reason of its elasticity in operation and the improved acceleration at starting.

The division between these two alternative methods of working the traffic on the sections under consideration has been carefully examined by the Superintendent, who has given us a list of the trains that are not suitable for multiple-unit working. The use of multiple-unit trains would be much more extensive on the branch lines than on the main line from London to Leeds. This is clearly shewn by the statistics of passenger train mileage in Table IV. The proportion for the main line is about 65 per cent. locomotive-hauled to 35 per cent. multiple-unit, and for the branch lines 15 per cent. locomotive-hauled to 85 per cent. multiple-unit.

In accordance with instructions, we have assumed no acceleration of the long-distance passenger trains hauled by locomotives. For the multiple-unit trains advantage has been taken of the rapid starting which is a feature of this system, and the average speed has been increased by 10 to 20 per cent. compared to present steam timings. For example, a train from King's Cross to Peterborough, stopping at 15 intermediate stations, now takes 2 hours 32 minutes; the electric timing, allowing for the same stops, would be 2 hours 8 minutes. Similarly, a train from Grantham to Boston, stopping at 5 intermediate stations, now takes 62 minutes; the electric timing would be 49 minutes. The motors would be designed for a maximum running speed not exceeding 60 miles per hour.

Apart from the regular passenger trains, there are from time to time a number of excursion trains. These would be hauled by electric locomotives, and, as specially high speeds are not essential, the stock of passenger locomotives would, so far as necessary, be supplemented by locomotives of a different class normally employed in hauling express goods. These locomotives would be suitable for a maximum speed of 60 miles per hour, and the average speed for a 12-coach train on a non-stop run, for example, between Peterborough and King's Cross would be about 50 miles per hour.

We have given careful consideration, with the officers of the Railway, to the working of the goods and mineral trains in order to see how far the advantages offered by electric operation can be realised under the special conditions prevailing in this country. These advantages arise from the practically unlimited locomotive power which can be provided without exceeding the restrictions which limit the dimensions, the weight per axle and the concentration of weight of the locomotives, and, but for other restrictions, would enable heavier trains to be hauled at greatly increased speeds.

So far as train weights are concerned, it is not considered advisable, on account of the strength of the standard draw gear, to make any increase in the maximum loads now hauled. The majority of trains are, however, much below the maximum in weight, and in so far as this is due to the limited capability of the steam locomotives now in use it would seem practicable to increase the average weight and thereby reduce the number of trains. This has been done in various schemes of electrification already carried out, e.g., in South Africa and India, with consequent gain to the working costs. We understand, however, that on the L.N.E.R. the weights of goods trains are settled partly by the lengths of refuge sidings and partly by the inconvenience or difficulty in delaying the despatch of trains from the marshalling yards until full loads have been made up. Our calculations have therefore been based on the present service so far as train weights and number of trains are concerned.

By reason of the same characteristic of electric traction, viz., the practically unlimited locomotive power available, it is possible to increase considerably the speeds of goods and mineral trains. In practice there are various factors which make it inadvisable to run unbraked trains at more than about 35 miles per hour, especially the liability for axle boxes to become overheated, and the difficulty of stopping trains when running down gradients by the braking power of the locomotive and the brake van alone. It is, however, quite practicable, given sufficiently powerful locomotives, to haul trains up the gradient at a much higher speed than is feasible to-day with steam locomotives. We have therefore assumed, with the concurrence of the officers of the Railway, that all unbraked goods trains would be hauled up the ruling gradient on each section at about 27 to 28 miles per hour, and that the speed on the level would be limited to about 33 miles per hour. Down the ruling gradient the speed would be reduced to such a value that the train could be brought to a standstill within the distance between the point where the distant signal is sighted and the home signal. With a mineral train of the maximum weight this speed would be about 25 miles per hour. The average speed for all non-stop unbraked goods and mineral trains would thus be about 30 miles per hour. This may be compared with the present-day speeds for trains of different classes between London and Peterborough as follows:—Class A. 23 to 24 miles per hour and Classes B. and C. 17 to 20 miles per hour.

The limitations mentioned above do not apply to express goods trains composed of wagons fitted with continuous brakes and oil-lubricated axle boxes. The present practice is to run these trains at speeds not exceeding 60 miles per hour for No. 1 Express goods, which consist only of braked vehicles, and 45 miles per hour for No. 2 Express goods, which contain only a certain proportion of braked vehicles. In our calculations we have adhered to these figures. For the No. 1 Express goods the electric timings would be the same as at present, but the average speed of the No. 2 Express goods would be somewhat increased.

Fresh timings in accordance with the foregoing particulars have been worked out for trains of all classes (except the long-distance locomotive-hauled passenger trains) on all sections. With these timings the Superintendent's Department have prepared a new set of time tables which form the basis for the calculation of several items in the estimates of Capital Outlay and Working Expenses. It is interesting to remark that these new time tables shew an annual saving in the time on journey (taking into account week-days only) of 24,087 hours (or 18.78 per cent.) for multiple-unit passenger trains, and 116,833 hours (or 18.0 per cent.) for goods and mineral trains.

The mileage worked by steam and electric locomotives are set out in Table III. and IV. As explained below, with the locomotives proposed all trains would have sufficient haulage power to run to schedule times without assistance. There would, therefore, be no necessity to include in the figures for engine mileage any allowance for "Assisting required." These figures, therefore, have been omitted for electric working of both passenger and goods traffic.

The figures for "shunting by shunting engine," "ballasting" and "departmental" are unaltered, but there would be a substantial reduction under electric working of the "'shed shunting." A large part of this work under present conditions is the movement of locomotive coal wagons; the remainder is the movement of "dead" engines. The former would, of course, be completely eliminated; and the latter considerably reduced, partly because shed work with electric locomotives is much less than with steam engines, and partly because electric locomotives generally move about under their own power. We have, therefore, with the agreement of the Railway, reduced the trailing ton miles and the engine miles under this heading to 10 per cent. of the steam figures.

TABLE III. Locomotive Working. (Steam).

Summary of Engine Miles.

Section.	London–Leeds (excluding Surburban Traffic as far as Welwyn Garden City).	Doncaster–March.	Grantham–Nottingham, and Grantham–Lincoln and Boston.	Peterboro'–Grimsby and Cleethorpes Skegness branch Mablethorpe Loop, Lincoln–Boston, Coningsby–Bellwater.	Total.
Passenger.					
Train	5,223,505	642,389	657,521	1,107,918	7,631,333
Shunting by train engines	36,417	7,207	12,236	48,562	104,422
Light	206,961	10,221	45,967	66,764	329,913
Assisting required ...	84,447	—	55	2,035	86,537
Assisting not required ...	6,060	660	—	4,805	11,525
Total	5,557,390	660,477	715,779	1,230,084	8,163,730
Goods.					
Train	4,445,290	1,634,615	726,946	608,862	7,413,713
Shunting by train engines	381,901	102,579	53,811	100,373	638,664
Light	389,478	76,220	96,223	51,332	613,253
Assisting required ...	11,158	617	11	—	11,786
Assisting not required ...	491	10,427	205	2,840	13,963
Total	5,228,318	1,824,458	877,196	761,407	8,691,379
Shunting by shunting engines.	2,904,496	293,785	414,980	309,608	3,922,869
Shed shunting	431,655	103,459	30,362	30,396	595,872
Ballasting	144,798	26,183	20,229	25,344	216,554
Departmental	170,171	8,991	16,983	12,652	208,797
Total	14,436,828	2,917,353	2,075,529	2,369,491	21,799,201

Electric Locomotives.

For hauling the heavy long distance passenger expresses we should propose a locomotive with four driving axles and a leading and trailing truck, having a total weight of about 110 to 115 tons, of which 72 tons would be on the drivers. This locomotive would be suitable for a normal maximum operating speed of 75 miles per hour, and at this speed would be capable of exerting a tractive effort of about 7,000 lb., or a drawbar pull (when running on the level) of 4,525 lb. It would be equipped with motors having an aggregate capacity (on the one hour rating) of about 2,400 h.p. As the centre of gravity would be comparatively high, all running parts completely balanced, and the motors fully spring borne, this locomotive would be easier on the track than any existing steam locomotive. It would be capable of working the heaviest trains to their present timings with a comfortable margin in hand to meet traffic delays, or bad weather conditions. It would be rather more powerful than necessary for the lighter expresses of say 350 tons, but we do not think there would be any economy in providing two different classes of high speed passenger engine as the slight extra cost of making them all alike would be offset by the better utilisation of the one

TABLE IV. Locomotive Working. (Electric).
Summary of Engine Miles.

Section.	London–Leeds (excluding Suburban Traffic as far as Welwyn Garden City).	Doncaster–March.	Grantham–Nottingham, and Grantham–Lincoln and Boston.	Peterboro' Grimsby and Cleethorpes Skegness branch, Mablethorpe Loop, Lincoln–Boston, Coningsby–Bellwater.	Total.
Passenger.					
Train.					
Locomotive	3,414,036	140,191	47,454	222,203	3,823,884
Multiple unit	1,809,469	502,198	610,067	885,715	3,807,449
Shunting by train engines.					
Locomotive	24,000	1,570	1,836	9,700	37,106
Multiple unit	12,417	5,637	10,400	38,862	67,316
Light	135,000	2,240	3,300	13,600	154,140
Assisting not required ...	4,000	140	—	950	5,090
Total	5,398,922	651,976	673,057	1,171,030	7,594,985
Goods.					
Train	4,445,290	1,634,615	726,946	606,862	7,413,713
Shunting by train engines.	381,901	102,579	53,811	100,373	638,664
Light	389,478	76,220	96,223	51,332	613,253
Assisting not required	491	10,427	205	2,840	13,963
Total	5,217,160	1,823,841	877,185	761,407	8,679,593
Shunting by shunting engines.	2,904,496	293,785	414,980	309,608	3,922,869
Shed shunting	43,165	10,345	3,036	3,039	59,585
Ballasting	144,798	26,183	20,229	25,344	216 554
Departmental	170,171	8,991	16,983	12,652	208,797
Total	13,878,712	2,815,121	2,005,470	2,283,080	20,982,383

class which enables the number of locomotives to be kept down to the minimum. Advantage might be taken of this extra power either to accelerate the lighter trains or to put in several intermediate stops while maintaining the present overall timing. For example, a train which now runs non-stop from King's Cross to Peterborough in 83 minutes could stop for 2 minutes at 4 intermediate stations, and still keep time. The electrical control of the motors would provide for several running speeds, and the locomotive could, if desired, work intermediate trips with goods trains of any class up to about 600 tons in weight at the speeds for which the vehicles are suitable.

The weights of goods train are so various, including the heaviest minerals and the lightest pick-up goods, that it would be uneconomical to provide only one class of goods locomotive. For unbraked goods, the weight of the locomotive available for braking must be sufficient to hold the train on a falling gradient, and bring it to rest at any signal against it. The heaviest trains consisting of loaded mineral wagons have a weight of 1,220 tons. For such trains a locomotive of 144 tons would be suitable to provide for the speeds mentioned above. Such a locomotive would have eight axles with 18 tons per axle, and each wheel would be fitted with two brake blocks. This would enable a 1,220-ton train, running down the ruling gradient of 1 in 200 at 25 miles per hour, to be brought to rest in 1,000 yards, even in wet weather.

According to the figures taken out for the sections considered the great majority, viz., 79 per cent., of goods trains are less than 600 tons in weight. Of the remaining 21 per cent., more than half do not exceed 900 tons. In order to deal economically with this diversity of traffic, we propose that two classes of locomotive should be provided, viz., Class A having two 4-wheel bogies, and Class B having two 6-wheel bogies. In both classes all axles would be driving axles, and the weight per axle would be 18 tons. Locomotives of Class A would be designed for multiple-unit working, and two such locomotives coupled together and controlled by a single driver would be used for trains of more than 900 tons. Trains not exceeding 600 tons on sections where the ruling gradient is not steeper than about 1 in 200 would be hauled by single Class A locomotives; trains weighing from 600 to 900 tons, and lighter trains on sections where the gradients are more severe than 1 in 200 would be hauled by single Class B locomotives. All locomotives of both classes would be equipped with the same motor, which would in all essential details be identical with the motors of the passenger locomotives.

These Class A and Class B locomotives would not be suitable for working express goods trains. They would not be designed for any higher train speed than 35 miles per hour, and would not be equipped with vacuum pumps for the operation of train brakes. We would propose, therefore, that the express goods trains should be hauled by modified Class B (6-axle) locomotives, referred to below as Class B1, the modifications consisting only in an alteration to the ratio of the gearing between the motors and the driving axles, and in the provision of an electrically driven vacuum

pump. These modified locomotives would be suitable for a maximum train speed of 60 miles per hour, and would have sufficient tractive effort for all express goods trains as now made up on all sections. Some of them, as already explained, would be used for hauling excursion trains, and when necessary would be fitted with boilers for heating the coaches.

There are throughout the system a considerable number of shunting locomotives employed in the goods yards at or near the principal stations and for shunting passenger trains. We have made a careful study of the question how to carry on this work most economically under electric conditions. At most places there are some tracks which are very seldom used by any locomotive, and in order to avoid unnecessary expenditure on the overhead line equipment for such tracks the suggestion has been made to employ a sufficient number of battery locomotives suitable for taking power from the overhead line when running on equipped tracks and from the battery when on tracks without overhead equipment. Such locomotives are, however, costly and comparatively inefficient, and in the conditions prevailing in the yards included in the present scheme we consider it preferable to equip all tracks on which locomotives may have to run, however seldom, and provide only electric shunting locomotives of the simplest design. These would be of the four-axle double-bogie type, weighing about 60 tons, and equipped with four 180 h.p. motors, giving a tractive effort of about 20,000 lbs. The control and grouping of the four motors would enable the locomotives to work economically at the speeds usual in shunting yards, and also at the higher speeds necessary when hauling trains from one yard to another, or from the carriage sidings to the terminal stations.

Electrical System and Track Equipment.

In accordance with the recommendation of the Ministry of Transport Committee on Electrification we have assumed that the 1,500 volt direct current system would be adopted, and that the track equipment would consist of overhead wires with the running rails bonded for the return circuit.

For all running lines the overhead equipment would be of the catenary design, with a copper section depending on the distance between substations, the number of tracks, the density of the traffic and the gradients. The accommodation of the live lines in tunnels and under low bridges has been the subject of special study by the Engineer on information which we have supplied We are informed that there are no insuperable difficulties, and his estimate for the necessary alterations is included in the Capital Estimates, Table V. The equipment of tracks in yards would be of a simpler and cheaper design, as in such places working speeds are always low.

The structures supporting the overhead line tend to obscure the view of the signals, especially on tangent track, where the track equipment as seen from the driving cab of the locomotive appears as a sort of tunnel. Experience on some electrified railways shows that very little alteration to the signals has been necessary, but it is considered advisable for this electrification scheme, on account of the short block sections and the high running speeds, to remodel all main line running signals and fit them with Lebby signal lights and on the less important branches to carry out such alterations and relocations as might be found necessary.

As the running rails would form part of the circuit for the traction current, it would no longer be possible to use the present system of direct current track circuiting. All relays and fittings would therefore be changed for others suitable for operation with alternating current. The supply of power for this purpose would be provided at the substations and distributed by an insulated cable.

All communication circuits which now work with an earthed return would have to be changed over to an insulated return, otherwise the traction current returning to the substations by the rails and the earth would cause serious interference. Apart from this, no extensive alterations, such as cabling all the circuits, would be necessary, as there would be no high voltage alternating current overhead lines along the track, and the ripples in the direct current carried by the contact lines would be so small that there would be no appreciable interference with the transmission of speech or signals. It may be mentioned, as bearing on this point, that in the main line electrification schemes in India and South Africa, in both of which the direct current system is in use, it has not been found necessary to cable the communication circuits which run parallel to the electrified lines. The Engineer has prepared an estimate of the cost of carrying out the necessary alterations, and his estimate is included in the item "Alterations to Ways and Works" in Table V.

Power Supply and Substations.

In accordance with the Committee's instructions, we have assumed for the purposes of this report that the Railway would purchase from the Central Electricity Board all power for traction as direct current at 1,500 volts, and for other purposes as three-phase or single-phase alternating current at 6,600 volts, or other suitable pressures, and the Board have requested us to base our calculations on a rate of 0.5*d.* per unit, subject to the Railway being responsible for the maintenance and operation of the substations, and for the payment of local rates, if any, thereon. This figure is given on the assumption that the load factor of the total demand would be not less than 50 per cent. Our experience with other electric railways shows that such a load factor would be obtained. The supply agreement would contain a coal clause providing for an increase or decrease in the price per unit corresponding to a rise or fall in the price of coal; the effect of any such adjustment is referred to below on page 46.

We have carefully considered the arrangements that will have to be made by the Railway for maintenance and operation, under the assumption, to which we understand the Board agree, that all substations would be equipped with automatic and remote control apparatus. The complete electrified section would be divided into several areas, and in each area there would be a Power Control office from which any converting set in any substation in the area would be started up or shut down and any feeder switch opened or closed. Each of these offices would be in charge of Power Controllers working in shifts, and would be connected by pilot circuits to all substations and track sectioning switch cabins in the area controlled therefrom, and by telephone with the

other offices of the organisation and of the traffic control. The pilot circuits would not only enable the Power Controller to carry out all necessary operations, but would also indicate to him the condition of the various converting sets and the positions, whether open or closed, of all switches. In the event of any trouble occurring, the Controller would communicate at once with the maintenance staff.

Auxiliary Power Supplies.

Apart from the main converting sets which deal only with the supply of direct current at 1,500 volts for traction purposes, each substation would be equipped with one or more static transformers for the supply of power for auxiliary purposes, such as signalling, station and yard lighting, capstans, cranes and pumping. An insulated cable, running the whole length of the track on the main line and on all branches would be connected to the auxiliary transformers in the substations, and would be tapped wherever necessary for the new signal lights and track circuits, and for lighting and power purposes at intermediate stations.

At many places electric power is already provided, at others gas and oil are in use. In the former few alterations would be necessary to adapt the installation to the new supply. In the latter, the stations would have to be wired and the necessary switchgear and fittings installed, and in some places where on the present system the consumption of gas or oil is very small, and the annual cost is very low, it would be difficult to prove any financial advantage by the conversion. This matter has been investigated by the Electrical Engineer for the purpose of this Report, and his estimates are included in the Tables of Capital Outlay and Working Expenses.

Heating and Lighting of Passenger Trains.

In all schemes for the electrification of main line railways, it is necessary to take into account the provision of means for heating passenger coaches in place of the steam previously supplied by the locomotive boiler. The most natural method is to fit all coaches with electric heaters, and this is always done on multiple-unit trains. It would, however, be a long time before all main line stock could be so fitted, as, due to interchange of traffic on different lines, there are on many trains coaches from other railways. There is also the possibility that coaches normally in use on the electrified sections may have to run on to lines where there is not enough traffic to justify electrification. It is clear, therefore, that provision must be made for supplying steam for heating, and the present heaters must be retained on all the Company's coaches which may still at times be hauled by steam locomotives.

All electric locomotives used for hauling passenger trains would, therefore, be fitted with a boiler of suitable capacity. Such a boiler may be fired by coke or oil fuel, or may be electric. The latter is rather more expensive in running cost, but in view of its advantages in regard to cleanliness, simplicity and absence of fire risk, it is, in our opinion, to be preferred. The alternative would be to attach to the locomotive during the winter months a special wagon fitted with a coke, or oil-fired boiler, but this would be very inconvenient from the traffic point of view, especially at terminal stations.

For the multiple-unit stock which does not run off the electrified lines, and which always has a supply of power available, there would be no objection to electric heating, and provision is made in the estimates for wiring and fitting all multiple-unit coaches with suitable heaters.

For the lighting of passenger trains we should propose to retain the present system except on the multiple stock which would be wired for taking supply from the motor coaches, in accordance with the usual practice.

TABLE V.

ESTIMATES OF CAPITAL EXPENDITURE.

Excluding Expenditure on Locomotives and Multiple Unit Train Equipments.

Item.	Description.	Estimated Cost.	
		£	£
1	Track equipment of 1355·62 miles of running track, and 589·26 miles of sidings, includiug bonding, switch cabins, feeder connections, auxiliary power cable, and pilot and telephone lines.		5,542,400*
2	Alterations to Ways aud Works:		
	a. Tunnels, bridges and structures	165,028	
	b. Telegraphs and Telephones	49,689	
	c. Signals	286,432	
	d. Track circuits	87,200	
			588,349
3	Alterations to running sheds and repair shops		118,000
4	Control and maintenance offices, electrical stores depots and staff quarters.		48,500
5	Spare parts and material for locomotives, multiple-unit train equipments, track equipment and sub-stations.		246,000
6	Alterations to existing auxiliary power and lighting installations.		119,074
7	Contingencies, engineering expenses and interest on capital during construction.		755,000
	Total		£7,417,323

* This estimate is calculated on a basis price for copper of £70 per ton, and is subject to adjustment at the rate of £13,300 for every £1 per ton by which the basis price differs from £70.

Estimates of Capital Expenditure.

The estimates of capital expenditure, excluding that on locomotives and multiple-unit train equipments, are set out in detail in Table V. In the following paragraphs are given notes on the various items.

Item 1.—Track equipment.—Full particulars of the lines to be equipped have already been given in Table I., and we have prepared our estimates on this basis, using schedule rates taken from recent contracts for similar work of large magnitude, adapted for the conditions of manufacture and erection in this country. Adequate allowances have been made for the special work at all junctions, bridges, etc. The cost under this item includes the overhead line, structures and foundations, track bonding, the feeders from the substations, the track sectioning switch cabins and connections thereto, the auxiliary power distributing cable, and the pilot and telephone lines for power control.

Item 2.—Alterations to Ways and Works. The estimates set out in Table V. are those supplied to us by the Engineer.

Item 3.—Alterations to Running Sheds and Repair Shops.—Minor alterations would be required at the Doncaster locomotive works for dealing with electrical repairs of the locomotives during heavy overhaul, and certain running sheds would be adapted for inspection and light repairs of locomotives during the lie-over periods. Provision would have to be made for inspection and maintenance of the multiple-unit trains, and we have included an allowance in the estimate under this item for two new running sheds suitable for this class of rolling stock.

Item 4.—Control and Maintenance Offices, Electrical Stores Depôts and Staff Quarters.—New office buildings would be required at the headquarters of the organisation instituted to take charge of the maintenance and operation of the substations and the maintenance of the track equipment. In these buildings there would be accommodation for the control switchboard, offices for the engineers and their technical and clerical staff, mess rooms and stores. Other buildings would be required at various centres to house the track equipment and substation spares, and a provisional sum is included for staff quarters in case adequate housing accommodation is not available at all the points where the new staff will be stationed.

Item 5.—Spare Parts and Material for Locomotives, Multiple-unit Train Equipments, Track Equipment and Substations.—All material used for maintenance is chargeable against revenue, but the initial stocks which are provided must be included in the capital estimates. We have therefore included under this item the cost of spare parts for the electric locomotives and trains, materials such as insulators, fittings, copper and steel wire, and a number of standard structures, bonds, etc., for the maintenance of the track equipment, and spare parts for the substations, for the maintenance of which the Railway will be responsible.

Item 6.—Alterations to Existing Auxiliary Power and Lighting Installations.—The estimate under this item has been worked out for this Report by the Electrical Engineer.

Item 7.—Contingencies, Engineering Expenses, and Interest on Capital during Construction.—Under this item an allowance of £285,000 is included to provide for unforeseen expenditure, a sum of £220,000 for engineering and administration costs, and £250,000 for interest at 5 per cent. per annum on capital outlay during the construction period before each part of the complete scheme comes into beneficial use.

Total Gross Capital Expenditure.—The total gross capital expenditure excluding that on locomotives and multiple-unit train equipments, is £7,417,323.

Number and Cost of Locomotives.

It has frequently been stated in regard to schemes for main line electrification that the cost of the electric locomotives required should not be included in the capital expenditure, on the ground that they would merely displace a number of steam locomotives of approximately equal total value which could be transferred to other sections of the Railway and utilised there to meet the demands of growing traffic, or to take the place of other locomotives due for scrapping under the normal renewal programme. It is not safe to make this assumption without investigation of the circumstances in each case. In some schemes for which such investigation has been made, the estimated credit value of the steam locomotives has been greater than that of the electric locomotives.

The number of electric locomotives to be included in an electrification scheme is sometimes estimated on the basis of the mileage which such locomotives can work per annum. It is well known, from practical experience, that electric locomotives can do, on the average, mileages of 70,000 to 100,000 per annum. Such a method of calculation is, however, too general to be satisfactory for any particular scheme. We have, therefore, arranged with the Railway that the numbers of electric locomotives of the different classes and multiple-unit trains required for actual service, should be estimated from the revised time tables, to which reference has been made above.

This has been done by the Superintendent's Department who have prepared new engine workings and calculated therefrom the number of locomotives of each class, adding thereto the number required for specials, excursion trains, and trains run in duplicate. To the number so obtained we have added the necessary allowance for spares, inspection and running repairs, and heavy repairs, such allowance being based on the experience of electrified railways already in operation. The number of shunting locomotives required for service has been agreed with the Railway, and for ballasting and departmental trains we have allowed 15 electric against 20 steam locomotives. A complete list is given in Table VI.

The prices for the locomotives of each class and of the multiple-unit equipments have been estimated by us, on the experience of recent contracts, taking into account the difference between prices for the home market and for export, and the effect on manufacturing costs of the large number required. The latter is an important consideration, especially if, as we propose, standardized designs are adopted for all locomotives in respect of traction motors, control

apparatus and auxiliary machines such as exhausters and compressors. For example, on the locomotives enumerated in Table VI., excluding the shunting locomotives, there would be 1,496 traction motors identical in all essential respects, about 8,500 unit switches, and so on. Assuming that this scheme is only one section of a general electrification of the Railways in this country, it would be possible to arrange for economical methods of manufacture of the large quantities required. It is assumed that the mechanical portions would be built in the Railway's locomotive workshops, and that the electrical equipments would be purchased. As a check on our own estimates, prices have been obtained from electrical manufacturers, and we think the estimates can be accepted as reliable.

The list of steam locomotives released in consequence of electrification is given in Table VII., together with the total amount to be provided for their renewal in accordance with the Chief Accountant's calculations, namely, £3,998,298. Comparing this figure with the total in Table VI. for electric locomotives, viz., £5,507,090, and assuming that it is correct to regard the renewal value of steam locomotives as the credit value (taking into account the fact that steam locomotives of an average age of between 21 and 22 years would be replaced by new electric locomotives), there would be a balance of £1,508,792 Capital Expenditure chargeable against electrification.

TABLE VI.

NUMBER AND COST OF ELECTRIC LOCOMOTIVES AND MULTIPLE UNIT TRAIN EQUIPMENTS.

Item.	Number.	Description.	Rate.	Total.
			£	£
1	35	Passenger locomotives	16,250	568,750
2	258	Motor coach equipments ... ... (i)	5,130	1,323,540
3	516	Trailer coach equipments... ... (ii)	420	216,720
4	178	Class A goods locomotives	7,860	1,399,080
5	32	Class B do. do.	11,570	370,240
6	28	Class B1 mixed traffic locomotives ...	11,490	321,720
7	14	Class B1 do do. do. with boilers.	12,000	168,000
8	75	Shunting locomotives for goods yards ...	7,080	531,000
9	63	do. do. for passenger train shunting.	7,780	490,140
10	15	Class A locomotives for ballasting and departmental trains.	7,860	117,900
		Total		£5,507,900

NOTE.—(i) This price includes the extra cost of providing motor bogies instead of ordinary carriage bogies, and wiring and fitting coaches for electric heaters.
(ii) This price includes the cost of alterations to the coach bodies, and wiring and fitting coaches for electric heaters.

TABLE VII.

NUMBER, TYPE, AGE AND ESTIMATED NETT RENEWAL VALUE OF STEAM LOCOMOTIVES DISPLACED BY ELECTRIFICATION.

Number.	Type.	Average Age.	Estimated Nett Renewal Value.
35	4-6-2 Tender	4·96 years	
23	4-6-0 „	20·23 „	
80	4-4-2 „	23·66 „	
96	4-4-0 „	27·28 „	
2	2-8-2 „	4·50 „	
133	2-8-0 „	11·98 „	
82	2-6-0 „	8·54 „	
27	0-8-0 „	23·03 „	
223	0-6-0 „	22·82 „	
1	Steam Rail Motor	1·08 „	£3,998,298
3	4-8-0 Tank	11·50 „	
2	4-6-2 „	15·37 „	
18	4-4-2 „	28·18 „	
2	2-6-4 „	13·80 „	
9	0-8-2 „	24·08 „	
1	0-6-4 „	24·83 „	
27	0-6-2 „	12·46 „	
159	0-6-0 „	31·34 „	
2	0-4-4 „	29·41 „	
925			

An alternative method of consideration is to base the estimate of credit on the annual expenditure by the Company on complete renewals of locomotives. The number renewed and the cost of such renewals during recent years are as follows:—

Year.	1925.	1926.	1927.	1928.	1929.
Number renewed	148	115	128	160	110
	£	£	£	£	£
Expenditure on renewals, including proportion of supervision and shop expenses.	678,450	446,849	406,677	592,979	448,880

On the average during the years 1925 to 1929 inclusive, 132 locomotives per annum have been renewed at a cost of £514,767, this number representing 1.8 per cent. of the total stock of about 7,400. It may be assumed that the electric locomotives will begin to displace steam locomotives two years after the start of construction, and that all the 925 steam locomotives will have been displaced three years later. During these three years there will be an expenditure of £1,835,697 per annum on electric locomotives and nothing on renewals of steam locomotives. Failing electrification the usual expenditure on renewals, viz., £514,767 per annum, would continue. Assuming that obsolescence or scrapping of steam locomotives in service continues at the rate of 132 per annum, there would be no need to begin steam locomotives renewals again for 7 years.

Allowing compound interest at 5 per cent. the saving of this annual amount for 7 years is equivalent to a saving of £1,094,000 per annum for 3 years. The net expenditure on locomotives is, therefore, £741,697 per annum (i.e., £1,835,697 minus £1,094,000) for 3 years, i.e., a total of £2,225,090 chargeable against electrification.

It will be noted that the average rate of renewal of steam locomotives, viz., 1.8 per cent. per annum is a good deal less than the rate based on the accepted life of 33⅓ years, i.e., 3 per cent. If the latter figure were worked to, the number replaced annually would be about 222, and assuming the same average price per locomotive the annual expenditure would be £866,000. At this rate renewals would begin again after 4.16 years, and on this basis the amount chargeable against electrification would be about £2,000,000.

Opinions may differ as to which of these methods of estimation should be adopted, but we think that taking all the circumstances into account it would be reasonable to debit the electrification scheme with a capital expenditure of £2,000,000 in respect of the electric locomotives and multiple-unit train equipments.

Credits for Released Assets other than Steam Locomotives.

Electrification will result in the release of certain buildings, plant and machinery, and other assets now required in connection with steam operation, and the Chief Accountant has supplied us with their values. Some items would be wholly dispensed with, as, for example, stocks of coal for locomotive purposes, but others, e.g., locomotive workshops and running sheds, would still be utilised, though to a smaller extent, under electric conditions. In such cases we have made the necessary adjustments to the figures, and the first column of Table VIII. shows the value of the portion of each item which would be released, after allowing for the requirements of the electric services.

The items may be divided into three groups—(*a*) those which are realisable to their full value, (*b*) those on which some proportion of their book value or renewal value is recoverable, and (*c*) those for which no practicable amount would be realised. The total of group (*a*) is £515,000, and this amount must be credited in full. The total of group (*b*) is £329,000. We have considered with the Chief Accountant what credit value should be taken for each of the items in this group, and the figures are given in the second column of Table VIII., the total being £256,000. The total of group (*c*) is £287,000, but we see no reason to assign any credit value to any of the items in this group.

The figures include a credit for 1,296 locomotive coal wagons which would be released for use in other services. There would also be some reduction in the number of companies' and traders' wagons due to the saving in running time which amounts to 4,900,000 wagon hours per annum. It is, however, difficult to make an actual estimate of this reduction, and no credit has, therefore, been taken on this account.

Net Capital Outlay.

Adding to the gross capital outlay as given in Table V., the amount chargeable for locomotives, and deducting the credits as set out in Table VIII., the net capital outlay is obtained. The figures are contained in Table IX., which shows that the net total is £8,646,323.

Working Expenses.

The working expenses with steam operation are set out in the first column of Table X., and are in accordance with information supplied to us by the Chief Accountant. The figures are based on the actual costs for the year 1929, with an increase of 2½ per cent. on the wages to correspond with the rates now in force. The costs under Item 1, Locomotive fuel, are calculated on the present price of coal and are subject to variation as the price varies; for each shilling per ton rise or fall the total under this item would be increased or decreased by £30,012. The various items of working expenses with electric operation are set out in the second column of the same Table. The following notes will explain how these estimates have been prepared.

Item 1.—Electric Power.—The cost of power is the largest item in the working expenses with electric operation, and it is therefore important that the figures should be accurately estimated.

TABLE VIII.

List and Values of Assets displaced by Electrification.

Item.	Description.	Book Value or Replacement Value.	Credit Value.
		£	£
Group (a).	95 coaches released by acceleration of service	85,000	85,000
	1,296 locomotive coal wagons	168,000	168,000
	Locomotive spare parts	200,000	200,000
	Coal stock	62,000	62,000
		515,000	515,000
Group (b)	Surplus plant and machinery in locomotive workshops ...	95,000	85,000
	Plant and machinery in surplus running sheds and pump-houses.	48,000	43,000
	Surplus permanent way at locomotive workshops	4,000	1,000
	Permanent way at surplus running sheds	41,000	7,000
	Coaling appliances	20,000	18.000
	Train lighting sets	113,000	102,000
		321,000	256,000
Group (c)	Land at locomotive workshops (portion) and surplus running sheds.	25,000	—
	Locomotive workshop buildings (portion)	49,000	—
	Surplus running shed buildings	124,000	—
	Surplus pumphouses, water-tanks, water mains, etc. ...	77,000	—
	Turntables	12,000	—
		287,000	—
	Total Credit ...	—	£771,000

TABLE IX.

Net Capital Outlay.

	£
Gross capital outlay (excluding locomotives and multiple unit train equipments), Table V.	7,417,323
Charge for locomotives and train equipments	2,000,000
	£9,417,323
Less credit Table VIII	771,000
Net capital outlay	£8,646,323

The principal basis of the calculation is the assumed tractive resistance for each class of rolling stock, locomotives, passenger coaches, and wagons with various tares and loads, under the different conditions of speed appropriate to each class. We have made a special study of this subject in the last 25 years, during which we have been connected with various railway electrification schemes, and have collected a large amount of information, partly from special tests and operating experience on these railways and partly from published and unpublished records of experience on other railways. We are confident, therefore, that the assumptions we have made are substantially correct. On the basis of these figures, as applied to the statistics of engine miles and trailing ton miles, we have calculated the annual energy consumption, and have added allowances for unbooked traffic delays, for bad weather conditions and for heating and lighting the passenger trains. The costs in the Table are derived from these calculations by multiplying the number of units by the price per unit referred to above and, as already mentioned, are subject to variation in the price of coal, a rise or fall of one shilling per ton corresponding to an increase or decrease in the total for this item of £10,558.

It will be noted that the cost of power for passenger and goods trains is higher than the cost of locomotive fuel, but that for shunting and departmental traffic there is a considerable saving by electrification. This difference is partly accounted for by the large reduction in shed shunting, but mainly by the economy of operation of electric shunting engines in goods yards and passenger sidings as compared with the low efficiency under such conditions of steam locomotives. There are, of course, no complete records of the actual work, in ton mileages, carried out by shunting locomotives; and in order that there should be no room for criticism of the calculated cost of electric energy for this work a special investigation was made at our request as to the average load moved, the average length of shunt, and the average speed, of several engines in yards selected as representative of all the goods yards on the system. The results of this investigation have been used as the basis for the calculation of ton mileage for goods shunting by shunting engines.

TABLE X.

Comparative Working Expenses, Steam and Electric.

Item.	——	Steam.		Electric.	
		£	£	£	£
1	Locomotive fuel (including haulage and handling) or electric power:—				
	Passenger traffic	171,583		261,000	
	Goods traffic...	247,918		283,330	
	Shunting and departmental traffic ...	105,368		42,900	
			524,869		586,620
2	Water for locomotive purposes:—				
	Passenger traffic	12,200		300	
	Goods traffic...	17,600		—	
	Shunting and departmental traffic ...	7,308		—	
			37,108		300
3	Lubricants for locomotives:—				
	Passenger traffic	4,223		1,770	
	Goods traffic...	4,565		1,580	
	Shunting and departmental traffic ...	2,121		530	
			10,909		3,880
4	Locomotive stores, clothing and miscellaneous:—				
	Passenger traffic	16,321		8,740	
	Goods traffic...	17,334		9,270	
	Shunting and departmental traffic ...	10,021		5,450	
			43,676		23,460
5	Drivers' and Firemen's wages and allowances, including relief and shed drivers and holidays:—				
	Passenger traffic	149,950		84,406	
	Goods traffic...	305,894		125,089	
	Shunting and departmental traffic ...	215,821		108,969	
			671,665		318,464
6	Locomotive cleaning, boiler washing shed and yard services:—				
	Passenger traffic	41,574		11,570	
	Goods traffic...	44,158		17,800	
	Shunting and departmental traffic ...	25,488		10,200	
			111,220		39,570
7	Supervision:—				
	Passenger traffic	10,786		7,000	
	Goods traffic...	11,119		7,200	
	Shunting and departmental traffic —	6,490		4,200	
			28,395		18,400
8	Locomotive repairs:—				
	Passenger traffic	136,076		77,480	
	Goods traffic...	209,597		75,670	
	Shunting and departmental traffic ...	93,020		34,270	
			438,693		187,420
9	Maintenance of engine sheds, watering appliances, etc.:—				
	Passenger traffic	5,442		2,170	
	Goods traffic...	5,794		2,310	
	Shunting and departmental traffic ...	3,296		1,320	
			14 532		5,800
10	Maintenance of train lighting sets... ...		17,028		—
11	Wages of guards, including allowances:—				
	Passenger traffic	40,201		34,722	
	Goods traffic...	128,944		105,670	
			169,145		140,392
12	National Insurance, workmen's compensation, superannuation and pensions.		32,218		14,900
13	Maintenance and operation of sub-stations		—		35,800
14	Maintenance of track equipment		—		97,380
15	Auxiliary power supplies and maintenance:—				
	Electric power	53,196			
	Gas	42,676			
	Oil	5,115			
	Hydraulic	2,500			
			103,487		57,994
16	Depreciation:—				
	Locomotives...	55,965		72,750	
	Track equipment	—		31,150	
			55,965		103,900
	Total		£2,258,910		£1,634,280

Difference in favour of electrification £624,630

Item 2.—Water for Locomotive Purposes.—The expenditure on water for locomotive purposes appearing in the steam working costs includes the cost of water purchased, and the working costs and repairs and renewals of the Railway-owned pumping stations and plant. It also includes the necessary expenditure on water cranes and columns. The figures relate to water for locomotive purposes only, and do not include any supplies for carriage washing and other purposes. The only water required for locomotive purposes with electric working will be that for heating trains. This will be a relatively small quantity, and could be taken from the same sources as that for carriage washing, etc. Practically the whole of the expenditure on water for locomotive purposes would thus be eliminated.

Item 3.—Lubricants.—The costs under this item have been estimated from experience with electric locomotives of similar designs, and multiple-unit trains, on a number of railways that have been in operation for some years.

Item 4.—Locomotive Stores, Clothing and Miscellaneous.—The locomotive stores are those required for cleaning locomotives, boiler washing, firelighting, and tube cleaning, engine lamps, tools and fittings and sand. There will be reductions in respect of cleaning material, lamps, tools and fittings, and boiler washing, etc., will be eliminated. With a reduced personnel the expenditure on clothing should be correspondingly reduced.

The item "miscellaneous" includes lighting of running sheds on which there should be a substantial reduction as a number of the existing sheds would no longer be used, and other general charges which would not be materially altered.

Item 5.—Drivers' and Firemen's Wages.—These costs have been estimated by the Superintendent in consultation with the Chief Accountant from the revised time tables showing electric working. Allowances have been included based on actual results with steam working adapted to electric conditions, for overtime, relief and shed drivers, and holidays. With the elimination of the coal-fired boilers, there would no longer be any necessity to provide two men on each locomotive; the equipment requires no attention during running, and one man is sufficient for the duties of driving. It is already customary to put one man in control of multiple-unit electric trains, and on electrified main lines on the Continent the principle is being extended to all trains excepting the long distance passenger expresses. To safeguard the train in the event of the motorman or driver being taken ill, a "dead man handle" would be provided, which would automatically cut off the power and apply the brakes. This device is available in different designs suitable for suburban multiple-unit trains, and for electric locomotives. The estimates have been worked out on the assumption that there would be a single driver on each multiple-unit train, goods train and shunting locomotive, but that there would be two men on each locomotive-hauled passenger train, though the second man need not necessarily be on the locomotive the whole of his time.

Item 6.—Locomotive Cleaning, Boiler Washing, Shed and Yard Services.—We have worked out the estimate for wages for cleaning electric locomotives which will be substantially less than the corresponding cost for steam locomotives, partly on account of the reduced number (the multiple-unit train requiring nothing special apart from the ordinary carriage cleaning), and partly due to the elimination of coal and steam. The boiler washing will be eliminated. The shed and yard services include wages in connection with engine lamps and tools, sanding expenses, stores issuing, regulation of enginemen's duties, and general labour, on all of which there will be some, though not considerable, reduction.

Item 7.—Supervision.—Under this item are included the wages and expenses at locomotive running sheds of inspectors, foremen, clerks and time-keepers. With a reduction in the number of sheds in use and in the number of drivers and firemen, there will be a proportionate saving under this head.

Item 8.—Locomotive Repairs.—There is a considerable body of information as to the cost of electric locomotive repairs, a good deal of which has not been published, but has been given to us privately. On the basis of this information we have made a careful estimate for the present scheme, and have included under this item materials, labour, supervision, shop expenses and upkeep of plant, for running repairs and for periodical heavy overhaul. Provision has been made for the renewal of parts subject to wear or deterioration thoughout an assumed life of $33\frac{1}{3}$ years.

Item 9.—Maintenance of Engine Sheds, Watering Appliances, etc.—Under this item are included the cost of wages and material for the maintenance of the civil engineering portion of engine sheds, workshops, turntables and other locomotive facilities. Due to the reduction in the number of locomotives, and the smaller amount of repair work necessary with electric working, a number of sheds will be dispensed with, and some part of the workshops will no longer be required. The turntables will no longer be necessary, as the electric locomotives can be driven equally well in either direction. Taking these considerations into account, we have made an estimate on the basis of the cost of steam working of the figure for electric working.

Item 10.—Maintenance of Train Lighting Sets.—With the conversion of a large number of passenger coaches for operation in multiple-unit trains, the expenditure on the maintenance of the dynamos and accumulators on these coaches would no longer be incurred.

Item 11.—Wages of Guards.—Due to the speeding up of the less important passenger trains and the goods trains, there would be a saving in respect of guards' wages. The costs under electric working have been estimated for us by the Superintendent in consultation with the Chief Accountant, and are given in the Table as received.

Item 12.—National Insurance, Workmen's Compensation, Superannuation and Pensions.—The expenditure under this item is in connection with drivers and firemen, all staff employed on the maintenance of engines, whether in the sheds or in the workshops, and guards. We have based the estimate for electric working on the expenditure for steam working, taking into account the reduction in the number of men required.

Item 13.—Maintenance and Operation of Substations.—We have worked out the complete organisation for the maintenance and operation of the substations, and have estimated the supervision and labour costs from information as to standard rates of pay supplied to us. We have also included a liberal estimate of the cost of materials required for maintenance purposes.

Item 14.—Maintenance of Track Equipment.—Similarly for the track equipment we have worked out a suitable organisation based on experience gathered from a number of electrified railways, and have calculated therefrom the cost of supervision and labour. The amount of material required for maintenance is normally quite small, but we have thought it prudent to make allowance for the complete renewal of all the contact wires every 20 years. These are the only wires subject to wear and tear.

Item 15.—Auxiliary Power Supplies.—Information has been compiled for us as to the power required for auxiliary purposes, including the installations (railway station and yard lighting, cranes, capstans, etc.), where electricity is already employed, and for others where gas, oil and hydraulic power are now used, and which would be converted. The maintenance costs under this item have been estimated for us by the Electrical Engineer's Department.

Item 16.—Depreciation.—We have calculated the annual amounts to be set aside for depreciation of the track equipment and electric locomotives on a sinking fund basis, taking compound interest at 4 per cent. per annum, as assumed by the Chief Accountant in preparing the figures for steam working.

For the electric locomotives and multiple-unit train equipments we have taken a life of 33⅓ years (the same as assumed for steam locomotives), and this requires an annual payment, on the basis mentioned above, of 1½ per cent. on the first cost, less scrap value.

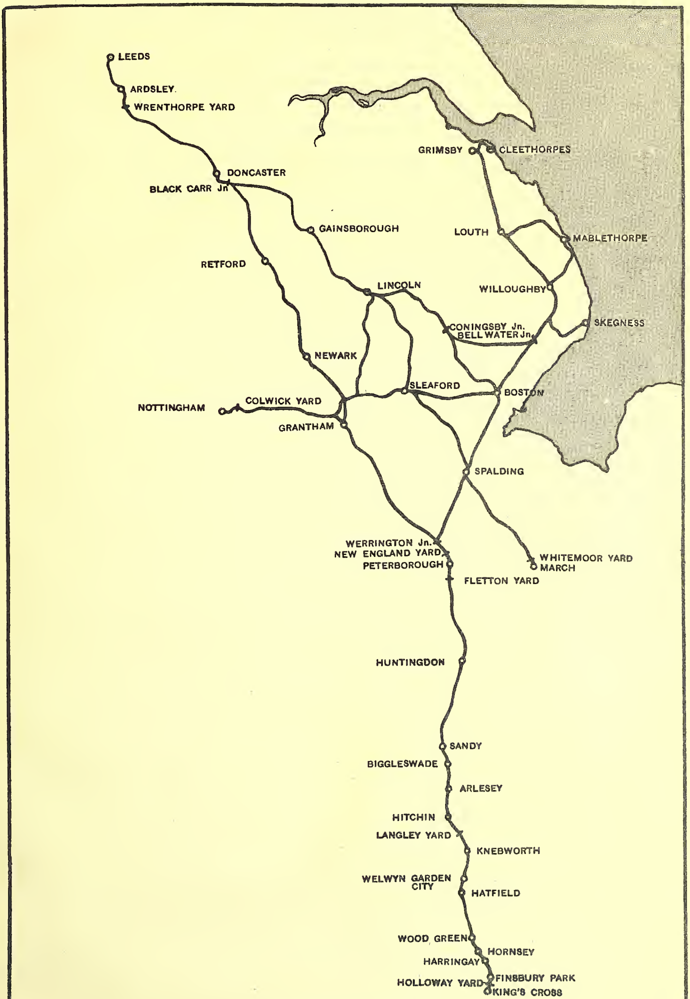
For the line equipment, consisting mainly of copper wires, steel structures, copper rail bonds, and a small amount of insulated cable, we have assumed a life of 50 years, i.e., 0.65 per cent. on the first cost less scrap value. For the track sectioning switches we have taken a life of 33⅓ years, i.e., 1½ per cent. on the first cost, the scrap value of this item being negligible.

Summary of Comparative Working Expenses and the Financial Result.

It will be seen from Table X. that the total of the comparable items of working expenses with steam operation is £2,258,910, and with electric working £1,634,280. The annual saving due to electrification is therefore £624,630. This is equal to 7.22 per cent. on the net capital expenditure of £8,646,323, and is available for payment of interest and any additional local rates for which the Railway may be liable in respect of the substations and the track equipment. For any variation in the price of coal from present rates, the annual saving will be affected to the extent of an increase or decrease of £19,454 for each shilling increase or decrease in the price per ton, equivalent to 0.225 per cent. on the net capital expenditure.

In carrying out this investigation we have kept throughout in close touch with the officers of the Railway, who, at the expense of much hard work, have prepared all necessary statistics of traffic, estimates of alterations to ways and works, steam working costs and valuation of assets. They have also drawn up revised time tables for electric working, have calculated for us on the basis of this revision two important items of the electric working costs, and have advised us as to the number of electric locomotives of different classes necessary for dealing with the traffic. We wish to express our appreciation of the way in which this work has been done.

MERZ AND McLELLAN.



LONDON & N.E. RAILWAY.
MAP OF ROUTES CONSIDERED IN THE REPORT

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APPENDIX V.

Report by Messrs. Merz and McLellan on the Electrification of a Portion of the London Midland and Scottish Railway.

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LIST OF TABLES INCLUDED IN THE REPORT.

PLATES ILLUSTRATING THE REPORT.

September, 1930.

THE SECRETARY,

RAILWAY ELECTRIFICATION COMMITTEE.

SIR,

We beg to submit herewith our Report on the electrification of a portion of the London, Midland and Scottish Railway, which we have investigated in collaboration with the railway officials in accordance with the Committee's instructions. The scheme, as suggested by the Company's representatives and approved by the Committee, includes the main line from Crewe to Carlisle, the line from Weaver Junction to Lime Street, Liverpool, and certain loops and minor branches connected with the main line. This section is one with certain rather heavy gradients and has a traffic density above the average—both factors usually favourable to electrification.

The Report gives full particulars of the traffic to be dealt with, the sub-division between steam and electric working of the traffic on the electrified sections, the proposed accelerations for all classes of traffic, estimates of gross and nett capital outlay on electrification, comparative estimates of steam and electrical operation and the financial result based on these figures.

Summarised very briefly, the figures are as follows:—

Total route mileage, about	193
Total single track mileage, including yards and sidings, about	843
Trailing ton miles, to be worked electrically, per annum, about	2,225,000,000
Engine miles, electric, per annum, about	7,947,000
Nett capital outlay	£5,123,370
Saving in working expenses	£127,766

representing 2.5 per cent. on the nett capital outlay.

From this saving of £127,766 per annum, must be deducted the increase, if any, in the local rates payable by the Railway Company in respect of the track equipment and the substations, which in the present circumstances, we have not attempted to estimate.

It will be seen from the foregoing figures that the saving resulting from electrification under the conditions laid down is not sufficient to pay the interest charges on the nett capital outlay. This result, in view of the conditions mentioned in the first paragraph, calls for some explanation. We have, therefore, in accordance with your wishes, made a further analysis of the conditions of operation, the results of which are set forth in our Report. The more important are as follows:—

(1) Although in other electrification schemes electric shunting has proved profitable, in the present case it was decided, initially, in order to limit the scope of the investigation, not to include any arrangements for electric shunting in the main goods yards, and to equip only the entrances to the sidings, so as to enable the train engines to haul their trains into the yards. The mileage of track to be so equipped, however, proved to be much greater than was expected, and the greater part of the sidings had to be included.

(2) The electric locomotives under this scheme would work an annual mileage of about half as much as electric locomotives can do, and actually are doing to-day on other systems. This is mainly due to:—

(*a*) The comparatively small size of the scheme.

(*b*) The amount of dual working (i.e., running part of a train journey with steam and part with electric locomotives).

Thus, while the distance from Crewe to Carlisle is 141 miles, the average length of electric locomotive run for booked passenger trains is only 43 miles, and for goods trains 42 miles. The average annual mileage is 35,000 against a possible 70,000 or 80,000. Some of the locomotives, moreover, would lie over between turns for 15 or 16 hours per day, thus increasing both the number required and the cost of the crews. The railway officers, as the result of a special investigation, find that the steam engines now running, wholly or partially, on the sections to be electrified, cover a total of 15,800,000 miles per annum, of which about 5,800,000 are on lines outside the scheme. To do this mileage 614 steam engines are now used, of which 379 would have to be retained after electrification, and 220 electric locomotives added. Thus, while electrification would eliminate 53 per cent. of the steam locomotive mileage, only 38 per cent. of the existing engines would be released, and the total number of locomotives would be reduced by only 2½ per cent. If the electrification scheme were more extensive, and adjacent sections were included, the locomotives would be used to better effect.

We trust that the Committee will find in this Report the information that they require, but we are at their disposal to elucidate any points on which they would like further information.

Yours faithfully,

MERZ AND McLELLAN.

LONDON, MIDLAND AND SCOTTISH RAILWAY ELECTRIFICATION.

This report deals with an investigation into a scheme of electrification for a portion of the London, Midland and Scottish Railway. The sections which are included in the scheme are shewn on the map in Plate I accompanying this report and comprise the line between Crewe and Carlisle (including the Winwick-Golbourne and Whelley loops), the line from Weaver Junction (16 miles north of Crewe) to Lime Street, Liverpool, and the branch lines to Windermere, Over and Wharton, Garston and Morecambe (N.W.R.). It has also been found necessary in order to provide for inter-running to include in the scheme the line from Lancaster to Morecambe and Heysham. This is at present partly worked electrically, on a single phase alternating current system, and would be re-equipped to conform with the other sections.

The selection of these lines was made with three considerations in view:—

(1) It was desired, principally, that the scheme should consist of main lines carrying heavy traffic in an area mainly industrial.

(2) It was considered advantageous to include lines with heavy gradients on which substantial economies might be expected due to the special features of electrical operation.

(3) It was to be assumed that electric working was limited to the lines considered, i.e., that the scheme was not to be regarded as part of a general electrification of the railways in this country.

In regard to these considerations, it should be remarked that, although the traffic on the sections selected is fairly heavy, the ton mileage per mile of route is a good deal less than on some other sections of the Railways in this country. The gradients on the line are comparatively severe, there being a stretch of 4 miles of 1 in 75 between Tebay and Shap Summit; there are also long stretches of 1 in 106, 1 in 125, and other gradients steeper than 1 in 200 on all parts of the line, the average over the 31 miles between Shap Summit and Carlisle being 1 in 195.

In regard to the third consideration, it was thought that on the sections selected only a small proportion of the traffic would still have to be worked by steam, and that there would be little alteration to existing working arrangements by reason of the change over from steam to electric locomotives at the terminal points. As the result of investigation, it has been found that this anticipation has only partly been realised, as will be seen from the particulars of traffic in Tables II and III. The change of locomotive at the terminal points has its effect on the extent to which the electric locomotives can be fully employed, and apart from this there are a number of intermediate points where a similar change is necessary if an excessive amount of steam working on the electrified lines is to be avoided.

In order to limit the scope of the investigation, it was decided initially not to include in the electrification scheme any arrangements for shunting in the main goods yards by electric shunting locomotives, and to equip only the entrances to the various sidings so as to enable train engines to haul their trains into the yards and leave them there to be broken up or marshalled by existing steam shunting locomotives. The Railway Officers indicated to us which tracks in the shunting yards and stations should be electrically equipped. The mileage of track to be equipped is much greater than we anticipated, in fact, the greater part of all the sidings at the terminal and principal intermediate stations (except in the Liverpool area) would have to be included. As an example of this it may be mentioned that at Crewe, which is regarded only as a terminal point where electric locomotives may pick up or deliver their trains, and run to and from the engine shed, track equipment is provided for 73 miles of running lines and sidings. The result of this decision is, therefore, that, although the goods yards are to a considerable extent equipped for electric working, advantage has not been taken of this to realise the economies resulting from the use of electric shunting locomotives.

The route and single track mileages are given in Table I.

TABLE I.

Route and Single Track Mileage.

Route Mileages.	
(1) Crewe—Carlisle ...	141·0
(2) Winwick—Golbourne Loop ...	3·3
(3) Whelly Loop ...	6·5
(4) Over and Wharton Branch ...	1·0
(5) Morecambe Branch (formerly L. & N.W.R.) ...	1·7
(6) Heysham—Morecambe—Lancaster Branch ...	8·9
(7) Windermere Branch ...	10·3
(8) Weaver Junction—Liverpool ...	19·4
(9) Garston Branch ...	1·3
Total ...	193·4
Single Track Mileages.	
Running lines and sidings in running lines ...	646·8
Traffic sidings ...	191·1
Traders' sidings ...	5·4
Total ...	843·3

TABLE II.

TRAFFIC STATISTICS.

Summary of Trailing Ton Mileages.

—	Present.	Proposed.	
	Steam.	Steam.	Electric.
Passenger	1,140,970,956*	212,618,314	928,352,642*
Freight	1,413,141,678	169,365,032	1,243,776,646
Departmental	51,395,760	11,165,940	40,229,820
Shunting by train engines	14,512,616	1,960,215	12,552,401
Total	2,620,021,010*	395,109,501	2,224,911,509*

* Includes 8,507,576 ton miles on the Heysham-Morecambe line worked by electricity.

Traffic Statistics.

Particulars of the traffic on the sections to be electrified have been taken out from the records and careful investigation has been made as to which trains running over the equipped lines should be electrically hauled and which should continue to be worked by steam. The principle followed in making this division is, in general, that trains to or from points off the electrified section which only run for a short distance on the electrified lines would continue to be worked by steam. All other trains would be worked electrically.

A summary of the trailing ton mileages is given in Table II., in the first column of which are the total ton mileages for the different classes of traffic which are worked on the lines in question at present. In Columns 2 and 3 these figures are sub-divided according to the proposed method of working, and it will be seen that, for the passenger traffic, nearly 20 per cent. of the trailing ton miles would continue to be worked by steam, and for freight traffic about 12 per cent.

Traffic Working.

After consultation with the officers of the Railway, it was decided that passenger traffic conditions were not suitable for the use of multiple-unit trains (apart from the existing electric service on the Heysham-Morecambe-Lancaster Branch), and that all passenger trains to be worked electrically should be hauled by electric locomotives. For the goods traffic there is no question in this investigation of any alternative method of working than by locomotive. Therefore, the electrification-scheme in this instance consists in the substitution for steam of electric locomotives of types suitable for the working conditions of the various classes of traffic.

Advantage has been taken of the possibility of providing locomotives of greater power than the steam locomotives in general use, to speed up all classes of traffic with electric working. This is effected by raising the average speed due to faster running up the gradients, but without any increase in the maximum speeds. The limiting speeds for the various classes of train (see notes to Table III.) have been taken as follows:—

	Miles per Hour.
Passenger trains ...	75
Fitted freight No. 1 ...	55
Fitted freight No. 2 ...	50
Express freight ...	40
Through freight ...	35
Empty wagon ...	30
Mineral ...	25

A comparison of the present net running times between Crewe and Carlisle with those proposed under the new conditions is given in Table III. Revised time tables have been prepared for the traffic on the electrified sections, which take into account all the traffic conditions. They show that in some instances the actual saving of time on the journey is much greater than the saving calculated from the present and proposed standard net timings, while in other instances it is less. Examples of the actual saving are given in the last column of Table III, which must be compared with the last column but one. These time tables have been used to determine the number of electric locomotives required, and to calculate the wages of the electric locomotive crews (as given in Table VIII).

TABLE III.

Comparison of Present Steam and Proposed Net Running Times.

Class of Train.		Present Standard Timing.		Proposed Standard Timing.		Proposed Acceleration.	Actual Acceleration for Sample Trains.
		hrs.	mins.	hrs.	mins.	mins.	mins.
Crewe to Carlisle.							
Passenger limited load	(1)	2	44	2	23	21	29½, 17, 21 / 25. 27, 25, 22
Passenger full load	(1)	2	58	2	23	35	39½, 28
Fitted freight No. 1.	(2)	3	48	3	1	47	—
Fitted freight No. 2	(3)	3	56	3	12	44	56, 68
Express freight ✠	(4)	4	41	4	16	25	155, 54, 139, 96
Express freight	(4)	5	10	4	28	42	33, 80
Through freight or empty wagon	(5)	5	56	4	33	83	33
Mineral	(6)	6	43	5	55	48	—
Carlisle to Crewe.							
Passenger limited load	(1)	2	55	2	20	35	38, 41, 36, 34
Passenger full load	(1)	3	8	2	20	48	43, 41, 44
Fitted freight No. 1	(2)	3	55	3	2	53	26
Fitted freight No. 2	(3)	4	0	3	11	49	105
Express freight ✠	(4)	4	42	4	21	21	105, 35
Express freight	(4)	5	18	4	30	48	—
Through freight or empty wagon	(5)	6	2	4	37	85	120, 75, –8
Mineral	(6)	6	44	5	54	50	—

(1) Passenger trains "limited load" include most of the long distance express trains. The "full load" trains are 10 to 15 per cent. heavier and somewhat slower.

(2) Fitted freight trains No. 1 must be piped throughout for automatic brakes, and the brakes must be operative on not less than half the wagons and the brake van. Vehicles must have close couplings and oil axle boxes.

(3) Fitted freight trains No. 2 must contain at least 50 per cent. of vehicles on which the automatic brakes are operative. The remainder of the train may consist of loose coupled unpiped vehicles, but the train must have oil axle boxes throughout.

(4) Express freight trains consist of general merchandise, and have no automatic brake except those marked ✠, which have 4 fitted vehicles next the engine.

(5) Through freight trains contain general merchandise, and have no automatic brake. Empty wagon trains need have no automatic brakes.

(6) Trains consisting of coal, iron, stone, sand, grain, potatoes and similar loads are classed as mineral trains. They have no automatic brakes.

The engine mileages, steam and electric, for the different classes of traffic, are set out in detail in Table IV. It will be noted that the total engine mileage on the electrified sections is about 6 per cent. less than under existing conditions. This difference is due to a reduction in the assisting required mileage and consequently in the light mileage. With the electric locomotives proposed, there should be no assisting at all for passenger trains, and for goods traffic only such banking as is called for by the regulations, which lay down that under certain circumstances there must be an engine at the rear of the train. It will be seen also that there is no difference in the respective figures of train mileage, neither coaching nor goods. In regard to the coaching traffic this calls for no comment, but it might be expected that something could be done in the way of increasing the average load of the goods trains, which is 421 tons, and thereby reducing the number of trains and consequently the cost of working. This matter has been carefully considered with the Railway Officers, who have pointed out after an investigation into a typical day's working that practically all trains are limited in weight, not by engine power, but by other considerations which are not affected by electrification. For example, many trains vary in weight during their journey by picking up and dropping numbers of wagons at intermediate points, so that although during part of the journey the weight of the train may be as high as the drawgear will permit, the average weight is comparatively small. It was decided therefore that no attempt should be made to revise the basis of goods train working except, as already mentioned, in respect of the speed of travel.

Electric Locomotives.

On a careful examination of the requirements of the passenger traffic and the train loads, we have come to the conclusion that two classes of electric passenger locomotive would be required. For the principal expresses between Crewe and Carlisle which may have a tare weight of 495 tons we should propose a locomotive with four driving axles and a leading and trailing truck, weighing about 110 to 115 tons. This would be equipped with motors having a total capacity of 2,400 horse power, and would be capable of hauling the heaviest trains up the 1 in 75 gradient without assistance, and of maintaining a steady speed of 70 miles per hour on the level. For lighter trains up to 380 tons tare weight a less powerful, and less expensive, locomotive of 1,800 horse power capacity would be suitable. This would be capable of the same performance with the lighter trains as the 2,400 horse power locomotive with the heaviest trains. It would also be used for fitted freight trains, and both classes of passenger locomotive would be used as convenient for specials.

As already mentioned, the weights of goods trains vary between wide limits. From a careful study of the records we should propose that except for a few small locomotives for banking and hauling departmental trains, one class of goods locomotive should be provided for all trains

except fitted freight No. 1 and No. 2. The small locomotive, referred to below as Class A would be of the four-axle double bogie type, with a weight of 72 tons and a capacity of 1,200 horse power. The goods locomotive, referred to as Class B, would also be of the double bogie type, but each bogie would have three driving axles and 3—350 horse power motors, making an aggregate capacity of 2,100 horse power. The total weight would be 108 tons.

Electrical System and Track Equipment.

We have assumed that the recommendation of the Ministry of Transport Committee on Electrification would be adopted and that all lines would be equipped with overhead wires for distribution to the trains of direct current at 1500 volts, and that the running rails would be used for the return circuit.

TABLE IV.

LOCOMOTIVE WORKING.

Summary of Engine Miles.

—	Existing Conditions.	Future Conditions.	
	Steam.	Steam.	Electric.
COACHING.			
Train	5,174,037*	976,174	4,197,863*
Shunting by train engines	19,422	3,327	16,095
Light	311,636†	60,102†	87,187†
Assisting required	124,702	22,603	—
Assisting not required	126,620	24,443	121,996
Total	5,756,417*	1,086,649	4,423,141*
GOODS.			
Train	3,334,688	376,654	2,958,034
Shunting by train engines	201,032	26,631	174,401
Light	431,678†	48,758†	165,838†
Assisting required	167,856	14,380	55,000
Assisting not required	64,090	7,239	51,894
Total	4,199,344	473,662	3,405,167
BALLASTING	130,198	27,994	102,204
OTHER DEPARTMENTAL	20,966	4,847	16,119
Total	10,106,925*	1,593,152	7,946,631*

* Includes 116,511 miles on the Heysham–Morecambe–Lancaster Branch worked by electricity.
† Including "Engine and Van" miles.

The overhead equipment for all running lines and for a proportion of the sidings would be of the catenary design; where practicable a simpler design would be adopted for groups of sidings where the conditions of working do not justify the higher cost of the more elaborate system. In many places slight alterations to existing structures would be necessary to provide sufficient space for the overhead lines; these alterations would involve the reconstruction and lifting of bridges, the lowering of tracks at a few points, and the removal of smoke boards. This matter has been examined in detail by the Chief Engineer, and his estimate of the cost of the alterations is given in Table VI. below.

It is important that with high speed working the overhead line structures should not obscure the signals. It is not always possible, even if it were desirable, to design the structures so as to permit a clear view of the signals from an adequate distance, and it would be necessary to provide special daylight electric signal lamps at many points. An estimate for these, for the alterations to existing signals and gantries, and for the provision of route indicators at junctions has been prepared by the Signal and Telegraph Engineer, and is included in Table VI. The present system of direct current track circuits would have to be altered to the alternating current system, as the rails would be used for the return in the main circuit. Alterations would also be required to the telegraph and telephone circuits to prevent interference with the new power lines. These would involve the provision wherever necessary of an insulated metallic return and the removal of earth connections from the rails; some of the present wires would have to be moved, and others at crossings cabled. The estimated cost of these alterations is given in Table VI.

Power Supply and Substations.

In accordance with the Committee's instructions, we have assumed that power for all purposes connected with this scheme would be purchased from the Central Electricity Board, who would provide the substations and wherever necessary, the secondary transmission lines between them and the grid substations, the Railway operating and maintaining the traction substations and paying the local rates thereon. The supply would thus be given by the Board for traction purposes as direct current at 1500 volts, and for other purposes as three phase or single phase alternating current at 6600 volts or other suitable pressures. The terms for the supply would be the subject

of negotiations and would naturally depend on a number of conditions, but we are authorised by the Board to state that the price would not be less than 0.5d. per unit. For the purpose of this report we have used this figure in our calculations.

The traction substations would be located at intervals of about 12 miles, and would be equipped with converting plant and switchgear for automatic operation on the supervisory control system. We should propose to arrange them in two groups, each group being connected to a control office at a convenient point near the centre. All switching operations in the substations and in the track sectioning switch cabins between the substations would be carried out by the Power Controllers at these two points by means of pilot circuits, which would also serve to indicate the position, whether open or closed, of every switch before and after any switching operation. These pilot circuits, together with two or three pairs of telephone wires to enable the Power Controllers to communicate with the maintenance staff and the Traffic Controllers, would be carried on the structures of the overhead track equipment.

Auxiliary Power Supplies.

With power at 0.5 penny per unit available at all points on the electrified sections, it would be profitable to utilise this supply for many auxiliary purposes which now take power from various sources, and to convert many steam, gas and oil installations to electric working. For this purpose, all substations would contain two auxiliary power transformers, one for continuous service and one as a standby, and three-phase or single-phase alternating current at 6600 volts or other convenient pressure would be distributed to all points on the electrified lines by an insulated cable, suspended from the track structures or laid along the track. This cable would be tapped wherever necessary for the supply to the new signal lights, the alternating current track circuits, and for lighting and power purposes at the various stations and goods yards. The estimated cost of alteration and conversion has been worked out by the Electrical Engineer in consultation with the Chief Accountant, who have also given us the consumption under the new conditions, and the present and revised costs of maintenance.

Heating of Passenger Trains.

Provision must be made for heating passenger trains during the winter months, and for a comparatively small scheme as this is, there is clearly no alternative to the system of steam heating which is in use throughout the Railway. It is necessary therefore to provide a boiler for each electrically hauled passenger train of sufficient capacity to heat the coaches to a reasonable temperature in the coldest weather. This boiler can be carried either on the electric locomotive or on a special truck; it can be either coke or oil fired or electrically fitted. Taking all the circumstances into account, simplicity of working, cleanliness, and freedom from fire risks in case of accident, we should recommend that an electric boiler should be included in the equipment of each passenger locomotive, and provision is made for this in the estimates.

Estimates of Capital Expenditure.

The estimates of capital expenditure are set out in detail in Tables VI and VII. The former shows the expenditure on, and connected with, electrification, apart from locomotives and multiple-unit train equipments; the latter gives the net capital outlay including the charge against the scheme for locomotives, as shown in Table V., and taking into account the credits for plant and other assets released.

Dealing first with the charge for locomotives as set out in Table V, the estimated cost per locomotive of each type has been worked out on the experience of recent contracts, with an allowance for the difference between prices for the home market and for export, assuming that the complete equipment would be purchased from electrical manufacturers, and that the mechanical portions would be built by the Railway in their own shops.

The number of electric locomotives required has been deduced from the engine working on the electrified sections with the revised time tables, with an allowance in each class for spares, inspection and running repairs, and periodical overhaul. It will be seen that in addition to the three motor and trailer coach equipments required to replace those now in service on the Heysham-Morecambe-Lancaster Branch the number of electric locomotives required would be 220. On comparing this with the annual engine mileage for all classes of traffic, viz., 7,830,120, it will be seen that the average annual mileage worked by each engine is only 35,000. This low figure is not due to any conditions inherent in the locomotives. It is well known from practical experience that electric locomotives are capable of working more than twice this mileage. We have therefore analysed the traffic conditions which determine how the locomotives are used. We find that there are a great many short runs for which electric engines must be provided; thus, although the distance from Crewe to Carlisle is 141 miles, the average length of journey for booked electric passenger trains is only 43 miles, and for electrically hauled goods trains 42 miles. It is clear therefore that, as the electrification scheme is restricted to the sections detailed above, there must necessarily be a great deal of lie-over time during which electric locomotives are waiting for trains. Such a state of affairs would not arise if the electrification were more extensive and included all, or practically all, the lines over a large area, as longer engine runs could be arranged, and there would be a better diversity in the incidence of traffic. There are, for instance, a number of electric locomotives which as part of their regular routine lie-over between turns for 15 or 16 hours per day. If adjacent sections were brought into the electrification scheme, a large part of the additional traffic could be dealt with by using the locomotives provided for the present scheme during their periods of lying over.

In order to determine the number of steam engines released, the Railway Officers examined all the workings of engines running either wholly or partially over the electrified sections. These include an engine mileage of about 15,800,000, about 5,800,000 being on sections not comprised in the electrification scheme, and under existing conditions of operation 614 engines are required. Although electrification would eliminate 53 per cent. of this steam worked engine mileage only 235 engines, or 38 per cent. of the existing number, would be released.

These conditions are illustrated by the diagram in Plate II. This shows engine runs for certain of the through passenger trains but is also typical of the arrangements for goods train working. Each composite line represents a continuous engine run under present conditions, and shows how the various runs would be divided under the new conditions, the red portions indicating electric working and the black the curtailed steam working.

The total cost of the electric locomotives and multiple-unit equipments is £2,830,450. The replacement cost of the steam locomotives released, as given to us by the Chief Accountant, is £1,094,222. As the expenditure by the Railway on complete renewals of locomotives is of the order of £1,000,000 per annum, and as the purchase and construction of electric locomotives would be spread over at least two years, there is no reason why the full value of the released locomotives should not be taken as a credit. The net charge against the electrification scheme on account of locomotives is, therefore, £1,736,228.

TABLE V.

NUMBER AND COST OF LOCOMOTIVES AND MULTIPLE UNIT TRAIN EQUIPMENTS.

Item.	Number.	Description.	Rate.	Total.
			£	£
1	57	Heavy Passenger Locomotives	16,250	926,250
2	64	Light " "	11.400	729,600
3	91	Class B locomotives	12,000	1,092,000
4	8	Class A locomotives	8,000	64,000
5	3	Motor and trailer coach equipments	6,200	18,600
		Total		£2,830,450
		Less		
	235	Steam locomotives released		£1,094,222*
		Net charge for locomotives		£1,736,228

* This figure includes the value of 3 motor coach equipments from the Heysham—Morecambe—Lancaster branch.

All other expenditure connected with the scheme is set out under the various items in Table VI., and the following paragraphs will provide such explanation as is necessary.

Item 1.—Track equipment.—Particulars of the lines included in the scheme for which equipment is required have already been given in Table I. The estimate is based on certain rates per mile for material, labour and supervision with allowances, decided on after personal inspection of the lines, for special work at junctions, stations, and goods yards. The whole of the overhead line is provided for, together with the track bonding, the cabins between substations with track sectioning switches, the main power connections to the overhead line from the substations and the switch cabins, the connections from the substations to the track rails, the auxiliary power cable and the supervisory control and telephone lines.

Item 2.—Alterations to Way and Works.—As already explained, certain alterations would be required to Bridges and Structures, and also to the Signalling system and Telegraph and Telephone lines. The estimates for these items have been supplied to us by the Chief Engineer and the Signal and Telegraph Engineer.

In working out the revised time-tables for electric operation, the Railway officers have found that additional facilities for changing engines would be required at Crewe and Preston, and they have supplied us with the estimate of the necessary expenditure.

Item 3.—Alterations to Running Sheds and Repair Shops.—Certain minor alterations for the accommodation and running repairs of electric locomotives would be required at nine engine sheds, and some additional equipment would be installed in the locomotive works for the periodical overhaul. For the former we have allowed £1,000 per shed, and for the latter £10,000.

Item 4.—Control and Maintenance Offices, Depots and Quarters.—Two control offices would be required with accommodation for the supervising engineers, power controllers and a portion of the maintenance staff. Other small depots would be distributed over the electrified sections for housing spare material for track equipment, bonds, etc. A provisional sum of £8,000 has been included to provide quarters for inspectors and other maintenance men at points where housing accommodation is not available.

Item 5.—Spare Parts.—Under this item are included the following amounts: £95,000 for locomotive spares, £20,000 for spare material for the track equipment and £15,000 for substation spares.

Item 6.—Alterations to Auxiliary Power and Lighting Installations.—This estimate has been worked out by the Electrical Engineer.

Item 7.—Contingencies, Engineering Expenses and Interest on Capital during Construction.—Under this item we have included £135,000 for unforeseen expenditure, £110,000 for engineering and administration costs during the construction period, and £120,000 for interest on capital expenditure before the scheme comes into beneficial use.

Total Gross Capital Expenditure.—The total expenditure on works connected with the electrification scheme, excluding the charge for locomotives, is £3,656,750, or including the charge for locomotives, £5,392,978. Against the latter must be put the credit for plant and other

assets released. The list of these assets and their values, as given to us by the Chief Accountant, is set out in Table VII., the total credit being £269,608. Thus the net capital expenditure on the scheme is £5,123,370.

TABLE VI.

ESTIMATES OF CAPITAL EXPENDITURE.

Excluding Expenditure on Locomotives and Multiple Unit Train Equipments.

Item.	Description.	Estimated Cost.	
		£	£
1	Track equipment of 646·8 miles of running track and 196·5 miles of sidings, including bonding, switch cabins, feeder connections, auxiliary power cable, and pilot and telephone lines.		2,519,550*
2	Alterations to Ways and Works:—		
	(a) Bridges and Structures	150,635	
	(b) Telegraphs and Telephones, Signals and Track Circuits	270,230	
	(c) Alterations at Crewe and Preston in connection with engine working	52,585	
			473,450
3	Alterations to running sheds and repair shops		19,000
4	Control and Maintenance offices, electrical stores, depots and staff quarters		24,750
5	Spare parts and material for locomotives, multiple unit train equipments, track equipment and sub-stations.		130,000
6	Alterations to existing auxiliary power and lighting installations ...		125,000
7	Contingencies, engineering expenses and interest on capital during construction.		365,000
	Total		£3,656,750

* This estimate is calculated on a basis price for copper of £70 per ton, and is subject to adjustment at the rate of £5,328 for every £1 per ton by which the basis price differs from £70.

TABLE VII.

NET CAPITAL EXPENDITURE.

	£	£
Gross capital expenditure (excluding locomotives), Table VI		3,656,750
Net charge for locomotives, Table V...		1,736,228
Total		£5,392,978
Less. Credits.		
Stocks of Coal and Stores	30,646	
Spare parts for locomotives, work in progress, etc.	104,520	
Water troughs	2,486	
Auxiliary power installations	131,956	
		269,608
Net capital expenditure		£5,123,370

Working Expenses.

The comparative annual costs of the traffic that would, when the scheme is put into operation, be worked electrically, are set out in Table VIII. The steam figures have been supplied to us by the Railway Officers, and we have ourselves estimated the various items of electric working cost (except the items for wages of locomotive crews and auxiliary power supplies which are referred to later) basing our estimate on the operation of similar equipment on electric railways elsewhere.

Before dealing in detail with the various items, we would point out that since this is only a partial electrification, and since there will be many steam trains still in use on the section and many steam locomotives stationed at the various sheds, it has been necessary to leave in certain costs which would have been eliminated had the electrification been complete. Speaking generally these are the costs designated by the Railway Accountants as "non-variable" costs, and they apply, as pointed out later, to expenses in connection with coaling and watering facilities, and engine sheds.

Item 1.—Locomotive fuel or electric power.—The cost of fuel for the steam service is based on the present price of coal, and includes carriage, not at the full public rate, but at the rate which it is estimated covers the actual cost to the Railway for performing this service.

The cost of electric power is based on the total ton mileage of each class of traffic and on the estimated consumption of energy per ton mile. This estimate takes into account the tractive resistances of the different kinds of rolling stock, including the locomotives, at the normal working speeds, the gradients, the average weather conditions, passenger train heating, and the losses in the overhead line and rails. The annual consumption ascertained in this manner has been charged at the rate of 0.5*d.* per unit, the total cost being £242,710.

Item 2.—Water for locomotive purposes.—The water required for washing down rolling stock has not been included on either side, and the cost for steam working is that for boiler water for steaming and washing out. The only requirements for water for the electric service will be for the small train heating boilers, and this amount is so small as to be almost negligible. A figure for this has been included, but the bulk of the £4,990 which appears in the table is due to "non-variable" charges on watering appliances which, although they will not be required for the electric engines, must be retained for the operation of the remaining steam service over the Line.

TABLE VIII.

COMPARATIVE WORKING EXPENSES, STEAM AND ELECTRIC.

Item.	——	Steam.		Electric.	
		£	£	£	£
1	Locomotive fuel (including haulage and handling) or electric power.		222,496		242,710
2	Water for locomotive purposes		14,115		4,990
3	Lubricants for locomotives		5,916		1,500
4	Locomotive stores, clothing and miscellaueous.		8,106		4,850
5	Drivers' and firemen's wages and allowances, including relief and shed drivers and holidays.		143,144		106,631
6	Locomotive cleaning		13,467		5,600
7	Other shed staff		24,178		17,300
8	Locomotive repairs		203,431		86,800
9	Shunting at sheds...		6,127		500
10	National insurance and workmen's compensation.		6,216		4,000
11	Maintenance and operation of sub-stations.		1,547		19,800
12	Maintenance of track equipment ...		1,152		43,100
13	Auxiliary power supplies and maintenauce.		117,640		82,946
14	Depreciation:—				
	Locomotives	31,871		36,975	
	Track equipment	292		14,722	
	Sub-stations	492		—	
			32,655		51,697
	Total		£800,190		£672,424

Difference in favour of electrification £127,766

Item 3.—Lubricants.—The quantity of oil for lubricating the electric engines has been estimated from figures in our possession relating to experience on a number of electrified railways.

Item 4.—Locomotive Stores, Clothing, Miscellaneous.—Under this heading are a number of Items such as materials for cleaning, boiler washing, fire lighting, engine lamps and tools. Some of these will be eliminated, and some reduced. The cost of clothing will also be less, not only on account of reduced personnel, but on account of the cleaner nature of the work.

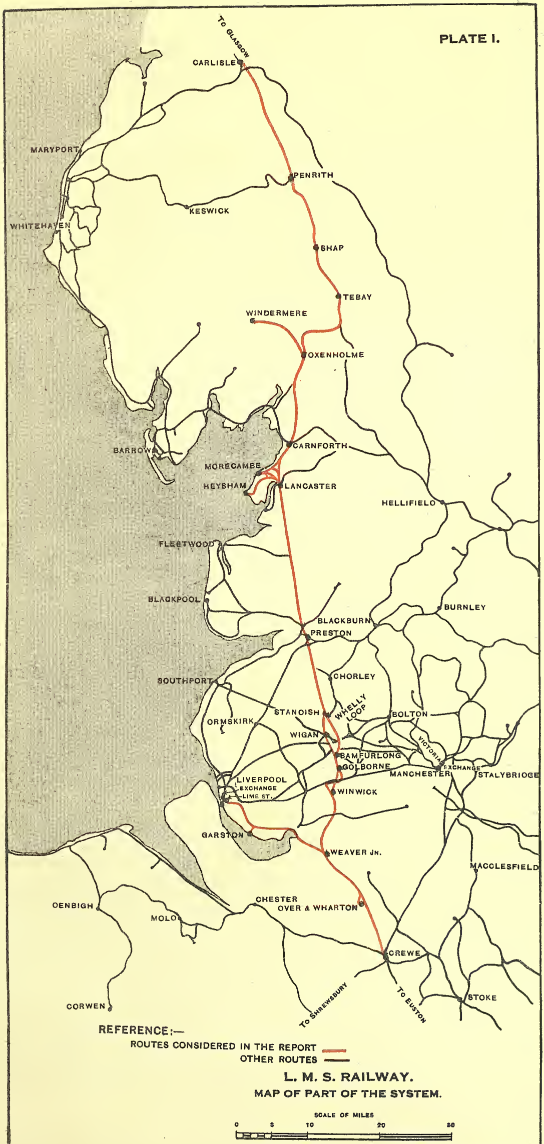
Item 5.—Drivers' and Firemen's Wages.—The cost of these wages for the steam service was ascertained by the Chief Accountant, and the cost for the electric service was estimated by the Chief General Superintendent's Department. This estimate was worked out in detail from the revised time tables, applying the same wage rates as for the present steam service.

Although the speed of the electrically hauled trains of all classes is substantially higher than the present speeds, this is not reflected to any marked extent in the wages of the enginemen. This is due to the fact that owing to the smallness of the section, and the shortness of the average engine run to which we have referred above, the arrangement of crews is not as economical as could be desired, and the actual cost of the steam and electric working (assuming the same number of men to be on the engine in both cases) is not very different. With the elimination of the coal-fired boilers, there would no longer be any necessity to provide two men on each locomotive. The equipment requires no attention during running, and one man is sufficient for the duties of driving. It is already customary to put one man in control of multiple-unit electric trains, and on electrified main lines on the Continent the principle is being extended to all trains excepting the long distance passenger expresses. To safeguard the train in the event of the motorman or driver being taken ill, a " dead man handle " would be provided, which would automatically cut off the power and apply the brakes. This device is available in different designs suitable for suburban multiple-unit trains, and for electric locomotives. The estimates have been worked out on the assumption that there would be a single driver on each multiple-unit train and goods train, but that there would be two men on each locomotive-hauled passenger train, though the second man need not necessarily be on the locomotive the whole of his time.

Item 6.—Locomotive Cleaning.—With the elimination of coal and steam, the expenditure on staff for cleaning engines would be considerably reduced. The figure included in Table VIII has been estimated on the basis of the staff employed elsewhere for similar work.

Item 7.—Other Shed Staff.—Boiler washing will be eliminated in the case of electric engines (except for a small amount in connection with the train heating boiler). The remainder of the cost under this item refers to foremen, oilers, and clerical and other labour at the sheds. In view of the fact that the electric engines visit the shed at much longer intervals than the steam locomotives, the staff required would be materially reduced by electrification.

Item 8.—Locomotive Repairs.—The figure for electric working includes all the work of repairs whether light or heavy and whether carried out at the running shed or the repair shop. We have made a special study of the cost of such work under various conditions and we are



L. M. S. RAILWAY.
MAP OF PART OF THE SYSTEM.

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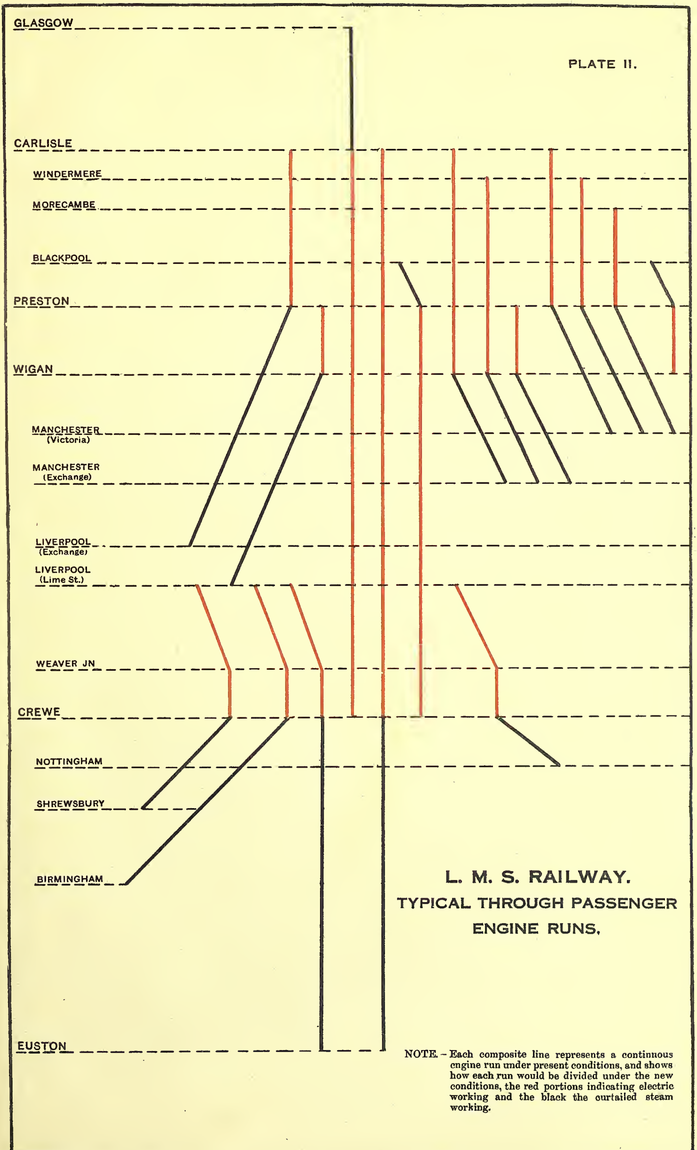

L. M. S. RAILWAY.

TYPICAL THROUGH PASSENGER ENGINE RUNS.

NOTE.—Each composite line represents a continuous engine run under present conditions, and shows how each run would be divided under the new conditions, the red portions indicating electric working and the black the curtailed steam working.

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confident that our estimates can be realized in practice. For the "non-variable" portion of workshop expenses we have taken the figure included in the costs for steam working although we consider that this is rather larger than would be necessary if the scheme had been part of a general electrification of the railways. This has already been referred to above.

Item 9.—Shunting at Sheds.—Shunting at sheds includes a great many movements mainly concerned with the coaling and watering of engines. With electric working the amount of shed shunting is very substantially reduced.

Item 10.—National Insurance and Workmen's Compensation.—The expenditure under this head relates to engine crews and to all men in workshops and in engine sheds, and has been estimated on the same basis as the cost for steam working.

Item 11.—Maintenance and Operation of Substations.—An estimate of the staff required for this purpose has been made and the costs are based on this, with an allowance for maintenance materials.

Item 12.—Maintenance of Track Equipment.—In this case also we have worked out a complete organisation based on what has proved to be necessary elsewhere, and the costs include the salaries, wages and other expenses of this organisation, and the necessary maintenance material. In estimating the expenditure on material, we have considered it prudent to provide for the replacement of the contact wire (the only part subject to wear) at the end of 20 years.

Item 13.—Auxiliary Power Supplies.—Information has been supplied to us as to the present cost of electricity used for auxiliary power purposes, and the cost of electricity, oil, gas or other fuel used for lighting and heating. These costs, together with the maintenance expenses of the various installations are included in this item for steam working. At our request the Electrical Engineer and the Chief Accountant have estimated the annual consumption of electricity for these services as well as the maintenance expenses which would be incurred if the power were taken from the traction substations. The total annual cost, on the basis of 0.5*d.* per unit, is included in this item for electric working. The capital cost of the change-over has been included in Table VI.

Item 14.—Depreciation.—For the electric locomotives we have taken an assumed life of 33⅓ years. For line equipment, which consists mainly of steel structures and copper wires, we have allowed a life of 50 years, and for the switchgear in the sectioning cabins a life of 33⅓ years. Scrap value, where this is appreciable, has been deducted and the depreciation worked out on original cost less scrap value, on the basis of a 4 per cent. per annum sinking fund.

Summary of Comparative Working Expenses and the Financial Result.

The total of the comparable items of working expenses with steam operation is £800,190, and with electric working £672,424. The annual saving due to electric working is therefore £127,766. This is equivalent to 2.5 per cent. on the net capital expenditure of £5,123,370. From this saving of £127,766 per annum must be deducted the amount payable in local rates on the substations and track equipment, and the balance would go toward the payment of interest on the net capital outlay.

In conclusion, we would like to express our appreciation of the assistance which has been given to us by the officers of the Railway who have spent a great deal of time in studying the problem and in preparing the information which we required for our calculations.

MERZ AND McLELLAN.

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